MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. LX.

EDITED BY

JAMES FORREST, Assoc. Inst. C.E., Secretary.

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ERRATA.

Vol. lviii., p. 320, lines 15 and 16, *for* "wood and iron" *read* "cast and wrought iron."

" " line 17, omit "the Crumlin viaduct."

" lix., p. 159, line 11 from bottom, *for* "every vessel *that floats*" *read* "every vessel *when lying still.*"

" " line 9 from bottom, *for* "displaces *her own weight in water*" *read* "displaces *a quantity of water represented by her length multiplied by her greatest submerged midship sections.*"

" p. 463, line 1, *for* "E. B. Williams" *read* "E. L. Williams."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1879-80.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

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13 January, 1880.

WILLIAM HENRY BARLOW, F.R.S., President, in the Chair.

THE following Associate Members have been transferred by the Council to the class of

Members.

CHARLES JOHN ALBRECHT.
CRAWFORD PETER BARLOW, B.A.
JOHN FLEMING CHURCHILL.
EDWARD JACKSON.
CHARLES PRIME.
JAMES SAMUEL STATTER.
RIENZI GIESMAN WALTON.
JAMES HENRY WHITTLE.

The following Candidates have been admitted by the Council as

Students.

GILBERT HAMILTON AINSLIE.
HENRY ARCHBALD, Jun.
ANDREW GEORGE ASHCROFT.
SIBLEY GEORGE BATTEN.
EDWIN JAMES BEAL.
HENRY OGLE BELL-IRVING.
PERCY BENHAM.
WILLIAM BRERETON BESTIC.
FRANCIS TREVOR BIRD.
REGINALD BLUNT.
GEORGE CECIL HERBERT BROWN.
CHARLES BROWNRIDGE.
LINDSAY BURNET.
LEONARD BURRELL.
OLIVER ROBERT HAWKE BURY.
ARTHUR DODWELL CHAPMAN.
JAMES BEMARDE CHIRNSIDE.
CHARLES COLE.
CHARLES JOHN PLUMBE COOMBS.
THOMAS DUNLOP.
GEORGE HOLLAND ERSKINE.
HENRY JOHN EUNSON.
WILLIAM ALBERT FENTON.
CHARLES HILTON HINGESTON, Jun.
FRANK GEERE HOWARD.
ISOJI ISHIGURO.
ERNEST IVE.
HARRY HERBERT LAKE.
HERBERT JOHN LANDON.
HUBERT LAWRENCE.
RUDOLPH EMIL VON LENGERKE.
EDWIN JAMES LOVEGROVE.

William Houldsworth McConnel.
John Richard MacGaohen.
George Harry le Maistre.
Ernest de Mérindol Malan.
Frederick William Maunsell.
John Henry Medlicott.
Arthur Meyrick Moore.
George Morison, Jun.
Keith William Murray.
Cuthbert James O'Brien.
Thomas William Potter.
Thomas Theophilus Prentice.
John Lambe Rigden.
William Fleet Robertson.
Henry Fillmer Rutter.
Robert Julian Scott.
Francis Martin Smith.
James Campbell Smith.
Alfred Wolryche Stansfeld.
Edmund Paley Stephenson.
John Henry Swainson.
Theodore Martin Teed.
Arthur Timmins.
Arthur Stuart Vowell.
George Kindersley Wasey,
William Watson, B.A.
Henry Arthur White.
Henry Wall Wilkinson.
Claude St. Maur Williams.
Gilbert Percy Williams.
Rowland Rice Williams.
Frederick James Wilson.

The following Candidates were balloted for and duly elected as :—

Members.

Henry Robert Pasley Carter.
Thomas Claxton Fidler.
Charles O'Neill.
Theophilus Seyrig.
Herbert Wallis.
Thomas Parker Watson, M.A.

Associate Members.

William Crickmay.
Godfry Darbishire, Stud. Inst. C.E.
Alexander Downie.
Joseph Francis.
Lionel Philip Payne Gallwey.
George Abraham Goodwin.
John Horan, B.E.
Hugh Giffen McKinney.
Adam Primrose.
Henry De Quincy Sewell.
John Standfield.
Reginald Foster Ward.
Henry Woolcock.
William Barton Worthington, B.Sc., Stud. Inst. C.E.

Associates.

William Martin Cuningham.
Joseph Montague Livesey.
William Hampson Topham.

Mr. Barlow addressed the Meeting in the following terms, on taking the chair, for the first time, after his election as President :—

The important rank which The Institution of Civil Engineers has acquired in this country, and the estimation in which it is held in foreign countries, while they are circumstances of which all must feel proud, necessarily impose upon its members, and especially on those who take a leading part in its affairs, duties

of corresponding responsibility. In assuming the position of President to which you have elected me, and for which my best thanks are due as being the highest honour my professional brethren can bestow, I feel it to be accompanied by obligations of so onerous a character, that I should have hesitated to undertake them, unless I could rely with confidence on your aid, not only to maintain, but if possible to raise, the standing which the Institution has attained.

It becomes my duty this evening to offer some observations in the nature of an address; but the variety of subjects which have been so ably treated by my predecessors in office render this task one of considerable difficulty.

Having commenced my professional career in the same year as that in which the Institution received its Royal Charter, namely 1828, I propose to draw attention to the great changes and progress in engineering which have arisen since that time; because those changes have had a marked effect on the conditions of daily life. It is in fact difficult for those who lived fifty years ago to recall all the circumstances of those times, so much have the facilities now enjoyed become a matter of habit; but it is not claiming too much to say, that some of the most important of those facilities are the direct result of the applications of engineering science.

There is one circumstance of my early life which left a strong impression on my mind, and which I may be pardoned for mentioning, namely, the first time I was present at a meeting of the Institution. This was in 1827. I went accompanied by my brother, Mr. P. W. Barlow, who was then an Associate, and is now one of our oldest Members. There were several men present whose names are well known, among them Mr. Joshua Field, Mr. James Simpson, Mr. (now Sir) John Macneill, and Mr. Henry Robinson Palmer. But the one who riveted my attention was the great Thomas Telford, who occupied the chair, and who seemed to me a superior being, gifted with higher attributes than ordinary men. It appears by the records of the Institution that the number of persons present at that meeting, including visitors, was twenty-three—and that was considered a well-attended meeting.

Of the large features of change since the Institution received its Royal Charter, there are none which have produced so marked an influence on the well-being of this country, and on the world at large, as the improvements in the means of communication, by the application of steam to locomotion on land and on sea, and by the utilisation of some of the powers of electricity in the transmission

of intelligence. It is not alone in the economical results, or in the impulse and larger area given to commercial enterprise, that advantage arises; but mutual interests become established between the inhabitants of different countries, people are induced to travel and enlarge their sphere of observation, dwellers in distant places are brought together, and the opportunities for interchange of ideas and thought are increased.

For some time previous to 1828, an improvement had been urgently demanded in the means of transport for goods and minerals. The canals, which in this country date from about the year 1758, were estimated, in 1836, to exceed 3,000 miles in length; but they were wholly inadequate to the wants of the commercial interests at that time. Much attention was bestowed on turnpike roads, many of the main lines having been brought to a high degree of excellence under the direction of Telford. Tramways, which existed long before canals, and in considerable numbers in the mineral districts, were mostly of cast iron, and belonged to private owners, few being applied to the general purposes of commerce. There were also some railways, distinguished from tramways, as their name implies, by being formed of rails instead of tramplates, among which was the well-known Stockton and Darlington Railway. The application of steam in locomotive engines was in an early experimental stage.

It is needless to mention George Stephenson. His name will always be associated with the early establishment of railways, not so much on account of the engineering ability he displayed, but because it was due to his strong convictions and his force of character, that the Liverpool and Manchester Railway Company adopted locomotive engines for their tractive power; and the commercial success of this enterprise formed the starting point of that great railway system which has spread its network and its ramifications in many parts of the world. That the discovery of a better system of locomotion by land was greatly needed is evinced by the extent to which the railway system has already been carried. The Liverpool and Manchester Railway was opened in 1830, and within forty-five years of that time Sir John Hawkshaw, Past-President Inst. C.E., in his address to the British Association,[1] estimated the total length of railways then existing at 160,000 miles, and the capital invested in their construction at £3,200

[1] Brit. Assoc. Rep., vol. xlv., 1875, pp. xcii. and xcix.

millions. Since then there have been considerable extensions; and when it is remembered that China has at present no railways, that Japan is only beginning to construct them, that Africa, with a population estimated by Mr. Brassey at between 350 and 400 millions, is almost without railways, as well as large parts of South America and Central Asia, and that many British colonies are badly provided, it must be obvious that the railway system will continue to increase. In the United States of America the construction of new lines is actively proceeding, and even in this country, which seems well supplied in proportion to its area and population, the increase proceeds, not so rapidly as it has done, but still it continues, as is evident from the following Table:—

	Miles.		£.
In the year 1846 the length was	2,765	and the traffic	7,565,569
„ „ 1854 „ „ „	8,053	„ „ „	20,215,724
„ „ 1862 „ „ „	11,551	„ „ „	29,128,558
„ „ 1870 „ „ „	15,537	„ „ „	45,078,143
„ „ 1878 „ „ „	17,333	„ „ „	62,862,674

The traffic receipts exhibit two separate elements of increase, one due to the greater length of lines in operation, the other to the continuous growth of traffic on lines already opened—a growth which is found to exist even on the oldest lines. It is not easy to separate these two elements in the traffic returns; but having devoted some pains to the inquiry, it appears that the traffic growth, on all the lines in the United Kingdom, over the whole period of thirty-two years, has averaged rather more than £100 per mile per annum. The traffic for the three years ending in 1878 has been almost stationary; but it was preceded by such very large receipts between 1870 and 1874 that at the date of the last annual returns, it was hardly back to its normal condition.

To meet the exigencies of this growth of traffic, a reconstruction of the permanent way, engines, and carriages has been necessary, as well as extensive additions to stations. The rails first laid were of wrought iron, weighing 35 lbs. per yard. Those now used on the main lines are of steel, weighing between 80 lbs. and 90 lbs. per yard, and on a large part of the principal railways four lines are laid, enabling the fast trains to be separated from those of lower speed, thus largely increasing the carrying capacity. The engines, originally limited to 5 tons in weight, and burning coke for fuel, have been replaced by others of greatly improved construction, weighing, with their tenders, from 50 to 75 tons, and burning a cheaper fuel, viz. coal. Carriages were first made after the pattern of coach-bodies, with three small compartments on four

wheels. These have been replaced by large commodious vehicles running on two six-wheeled bogie frames, and the Pullman carriage from America, with its drawing-room car and sleeping compartments, has been successfully introduced. While these improvements have added much to the comfort of railway travelling, a complete system of block-signalling, the employment of continuous brakes, and the interlocking of points and signals, have greatly increased the safety, notwithstanding the higher speed and the greater number of trains.

It is impossible to allude to railway travelling at this time, without the mind recurring to the late most lamentable accident at the Tay Bridge. This grave disaster is now the subject of a searching investigation, the results of which will necessarily be looked for with great anxiety. Should this inquiry reveal, as it may be hoped to do, the probable cause or causes which have contributed to such distressing results, it will afford information of the greatest value for future guidance.

Excepting this one unprecedented catastrophe, railway travelling exhibits highly satisfactory results as regards safety—whether considered in reference to the enormous numbers who travel, or to the distances accomplished by habitual travellers. The distances passed over by some of the older servants of the railway companies are remarkable. Thus, Mr. Allport states that guards on the Midland have ridden 2,000,000 miles, while Mr. Besley mentions two guards on the Great Western, one of whom is estimated to have travelled 2,400,000 miles, and the other 2,500,000 miles, a distance more than ten times that of the moon from the earth.

Street tramways, which have been in use for a long time in America, are now being largely introduced into the principal cities and towns of Europe. They are evidently a great convenience to a considerable class of the public; but whether from the mode of their construction or from insufficient care in the maintenance of the roads, some of them render the travelling of other carriages along the same lines of roads very unpleasant—a defect which it is hoped may be remedied. Efforts are being made to introduce some power upon them other than horse-traction. Among these are a modified form of the locomotive steam-engine, the compressed-air engine, and an ingenious arrangement called the fireless engine.

Steam navigation had made some progress in 1828. The number of steam vessels then existing was 344, with an aggregate tonnage of 30,912 tons, showing an average of about 90 tons

each. They were chiefly employed in river and coasting traffic. In the United States of America further progress had been made, the magnificent rivers of that country being among the earliest means developed for internal communication. At that time all ships, including ships of war, were of timber. With a few exceptions steam had not been introduced into the Royal Navy, and it was considered derogatory in the service to be appointed to the command of a steam vessel. Ocean steam navigation, which now forms the links of communication between distant countries, had not been attempted, and it constitutes another of those great achievements due to the application of steam to locomotion.

As the Liverpool and Manchester Railway was the starting point of the railway system, so were the almost simultaneous voyages of the "Sirius" and the "Great Western" in 1838 the starting point of ocean steam navigation. Its commercial success and the extent to which it has been carried are owing to improvements which involve a greater range of scientific knowledge than the construction of railways, and are the result of deep thought and unremitting perseverance of many able men. By improvements in the marine engine the consumption of fuel has been largely reduced; the screw-propeller has taken the place of the paddle-wheel, by which greater advantages in propulsion have been obtained; and by the substitution of iron and steel for timber, ships are now made of greater length and strength and carrying capacity.

The capital invested in ocean steamships, though large, has not been of the magnitude required for railways, but it is rapidly increasing, owing to the greater number of ships employed and to their being of larger dimensions and power. It appears that prior to 1836 the largest ships afloat were between 800 and 900 tons burthen, and about 220 HP. With the exception of the "Great Eastern," which, though grand in its conception, was in advance of the wants of the day, there has been an almost continuous growth in the dimensions and power employed. There is now in course of construction, entirely of Siemens-Martin steel, and nearly completed, the steamship "Servia," for the Cunard Company, of 7,500 tons burthen, 10,000 HP., 500 feet in length, and calculated for a speed of 17½ knots per hour. The Allan Company is building another vessel of 5,500 tons burthen, also to be entirely of steel. These will, however, be surpassed in magnitude by the war ships now building. The "Inflexible," for the English navy, will be 11,600 tons burthen, 8,000 HP., and carry four 80-ton guns; and the "Italia," for the Italian navy, will be 13,200 tons burthen, 18,000 HP., and carry four 100-ton guns.

The great ocean steamships, combining sailing and steam propulsion, present in their structure, and in the various requirements necessary for the speed, regularity, and safety with which they are worked, a number of mechanical and scientific applications of high order, every one of which is the result of much study and mental labour. But the ponderous armour-plated turret-ships, mounted with powerful artillery, containing steam-engines for propulsion, others for turning the turrets, for steering, lifting anchors, working hydraulic machinery for moving the guns, and numerous applications of electricity for signalling and firing and electric lighting, constitute as a whole a most surprising combination of science and skill. In these ships the improvements are of two kinds, one directed to the ship itself, its structure and its propulsion, the other to performing different functions of manipulation; and as regards these latter, admitting the excellence of each of the individual contrivances, yet there is a point at which their advantages may be overbalanced by their number and complexity.

The extension of navigation has rendered necessary a considerable increase in docks and harbour works. These works, some of them of great magnitude and cost, are too numerous to be described in detail. They constitute a special branch of engineering of a very important character. Large extensions of docks have been made in London, Liverpool, Southampton, and Hull. New docks have been constructed at Avonmouth and at Portishead in connection with Bristol, besides many other like works in different localities. Among the principal harbour works are those of Portland, Holyhead, and Dublin. The progress in harbours, however, does not appear to have proceeded so rapidly as to meet the full requirements of the time. The number of wrecks that occur annually within British waters seems to show that more harbours of refuge are required on the coasts of the United Kingdom, and there is evidence that the development of steam navigation is impeded by an insufficiency of harbours. This is especially observable in regard to the communication between England and the Continent. The Channel passage, from its extreme discomfort, interferes prejudicially with the proper interchange of traffic between those countries, and has led to many suggestions for its amendment. It is satisfactory to learn that the French Government is about to improve the harbours on the coast of France—a movement which it is hoped will be followed by corresponding action on the part of the English Government. The steamboat called the "Calais-Douvres" is a praiseworthy, and to a certain extent successful,

attempt to make the best of the existing harbours, and to mitigate some of the inconveniences of this short sea passage; but this vessel only runs during summer, and the greater room and superior accommodation afforded by her is not attainable in the rough winter months.

Canals have ceased to extend in England, to any appreciable degree, since the establishment of the railway system; but they progress in many parts of Europe, where, in conjunction with river navigation, they afford great facilities for trade carried on in small vessels. The most remarkable work of inland navigation of modern times, one which has exercised a great influence on the ocean navigation of the East, is the Suez ship canal—a work which will always render famous the name of its author, M. de Lesseps. Another similar work affecting the trade of Eastern Europe is the deepening of the mouths of the Danube, by Sir Charles Hartley, M. Inst. C.E. There are also two important American works, not yet entirely completed, one the deepening of the channel between Long Island and the mainland, rendered specially interesting by the extensive blasting operations at Hell Gate; the other the improvement and deepening of the south channel of the Mississippi, by Mr. J. B. Eads, M. Inst. C.E. In this work, by the application of comparatively inexpensive means, the channel has been deepened so as to permit the passage of much larger ships to New Orleans.

The communication of public and private intelligence was formerly dependent on the speed at which a man could travel, and, excepting a limited application of the old semaphores, the Government were in like manner restricted in their intelligence department. The introduction of electricity for the purposes of telegraphy, and more recently for the production of light, and lastly for the transmission of power, is a matter of especial interest, as being one in which the labours of the philosopher, and the discoveries originating in his laboratory, are made directly applicable "for the use and convenience of man." As in many other discoveries and new applications of science, the form which the telegraph ultimately received was preceded by various suggestions, showing the conception of the idea. Sir Francis Ronalds, as is well known, made a telegraph worked by frictional electricity, of which he published an account in 1823. A much nearer approach to the needle telegraph was an experiment by my father (Professor Barlow), who used a galvanic battery, and deflected small compass needles placed in different parts along the conducting wire. By

this experiment, which was recorded in the "Edinburgh Philosophical Journal for 1825," Professor Barlow found that considerable loss of power arose with increase of length, and he was in consequence discouraged from proceeding further than determining some of the laws on which that decrease depended, and also the relative conductivities of different sizes of brass or copper wire. Having been present at the experiment, I well remember, though only a lad at the time, that the large quantity battery, which had been employed in Professor Barlow's experiments on electro-magnetism, was used without any coil, and that the wires were hung to the posts without any insulation.

The form which the telegraph received at the hands of Sir Charles Wheatstone and Sir William Fothergill Cooke, and its application to signalling on the Blackwall railway in 1838, established its practicability. Through the influence of Mr. Robert Stephenson and of Mr. Bidder, Past-Presidents Inst. C.E., a company was formed to work the invention for commercial purposes, and from that time, by the aid of numerous inventions and adaptations, and especially by having overcome the difficulty of crossing the ocean, the system has spread with a rapidity to which there is no parallel. In 1875, the total length of wire in operation was estimated at 400,000 miles. Since then the Eastern Telegraph Company has extended its lines to the Cape of Good Hope; two new cables have been laid by Dr. Siemens, M. Inst. C.E., between France and America, and large extensions and duplications of land lines have been made. There are no means of tracing the traffic growth of telegraphy; but by the introduction of the duplex system and the automatic working, together with other ingenious contrivances, the traffic must have increased in a far greater proportion than the length of wire in operation. The diminution of power, arising from increase of length in the conducting wire, as pointed out by my father in 1825, renders it necessary to retransmit telegrams at the end of long cables. On land lines, or in short cables working in connection with land lines, this difficulty has been surmounted by relays of power applied at fixed stations. By employing this ingenious expedient on the Indo-European telegraph, Calcutta has frequently been put into direct communication with London, a distance of 7,000 miles. Another application of the telegraph, now commencing in this country, but already in considerable use in America, is the telephone, first publicly exhibited by Professor Bell at the Philadelphia Exhibition in 1876. The power of transmitting the sound of the human voice and its articulation gives it a high scientific interest. Its

value as a commercial instrument consists in saving the time required to write, transmit and re-write telegrams. Since the date of the telephone, Mr. E. A. Cowper, M. Inst. C.E., has succeeded in making a most ingenious instrument, whereby handwriting is transmitted and reproduced at the receiving station by telegraph. To Professor Morse is due what may be termed an extremely "happy thought," namely, the system called the "dot and dash." It constitutes a species of articulation, which conveys intelligible meaning by the relative intervals of continuance and discontinuance of action. It is applied in telegraphy, both in writing and in conveying messages by sound as well as by sight, and Sir William Thomson, M. Inst. C.E., has for some time past urged its adoption, where it would be of the greatest importance to the safety of navigation, namely, as a means of distinguishing lighthouses.

The brilliant electric light, which, in its present form, originated with the discoveries of Faraday, has latterly attracted much public attention. Some attempts were made to utilise this light when its source was derived from galvanic batteries, in which manner it was first produced by Sir Humphrey Davy; but the more recent electro-dynamic machines have placed lighting by electricity on a totally different footing to that on which it formerly stood. The exhibitions of this light in this city and in other cities during the last year, and the valuable evidence given in the Report from the Select Committee of the House of Commons of last session on Lighting by Electricity, leave no doubt of its applicability to many important purposes. It is, in fact, already established in lighthouses, where its intensity and power are of the highest value; and there are many examples of its application in public buildings and large shops, in railway stations and open spaces, and for street lighting. Whether it can be divided, so as to become equally economical and convenient for domestic purposes, has yet to be ascertained. In the evidence given before the Select Committee, and in the Report itself, there appears to be some confusion between the intensity of light and its illuminating power. The distinction ought not to be overlooked. The intensity of a light bears the same kind of relation to its illuminating power as the specific gravity of a substance does to its weight. Many powerful minds are now directing their attention to electric lighting, and there is daily evidence of its improvement and advance. The 20-HP. engine put down last year to work twenty lights in its immediate vicinity on the Thames Embankment has, by improvements since that time, been made to work sixty lights,

some of them at a distance of more than 1½ mile measured along the conducting wire.

The latest application of electricity, namely, for the transmission of mechanical energy, was suggested by Dr. Siemens, in his address to the Iron and Steel Institute in 1877. The laws which govern the size of the conductor, and other features as to its economy as a transmitter, were fully explained at a subsequent meeting of this Institution, and have since received practical confirmation. Sir William Armstrong, V.-P. Inst. C.E., has availed himself of this force for working a circular saw placed at a distance of one mile from the waterfall which supplies the power. The deep-sea sounding line on board the telegraph ship "Faraday" is hoisted by mechanical energy thus transmitted from the engine; and Dr. Werner Siemens has succeeded in obtaining locomotive power sufficient to convey thirty persons by similar means. It appears that, including all sources of loss from converting and reconverting the energy, from friction in the machines and from resistance in the conductor, Dr. Siemens has ascertained that 50 per cent. of the original power can be realised at a distance of one mile, and that, with adequate provisions against heating, it will be no dearer to transmit electro-motive power to a greater than to a smaller distance.

The subject of improved communications have been treated at some length because, except printing and the steam engine, no applications of physical science appear to have produced such extensive and important effects. The penny postage, for which the name of Sir Rowland Hill will always be renowned in the annals of this country, could not have existed without the aid of railways. Neither would it have been possible without their aid, combined with that of telegraphs, to circulate over large areas, newspapers at the cost of one penny, containing telegraphic information of events which happened in distant parts of the world on the day of their publication.

The subjects of artillery and armour plates were ably brought forward twelve years ago in the address of Mr. Charles Hutton Gregory, C.M.G., Past-President Inst. C.E. Since that time the contest between guns and plates, and the unavoidable competition among nations for superiority of armaments, have led to gigantic apparatus for attack and defence. As the magnitude and power of guns have increased, changes have been required in the metal employed in their construction. In 1828 the largest guns and mortars were of cast iron. In the next stage of advancement

wrought iron was used. And now that guns weighing 80 tons and 100 tons are constructed, the metal employed is steel, which is universal, at least so far as regards its adoption for the interior lining. The controversial questions as to the employment of steel for the whole gun, instead of a lining of steel with an iron covering, and as to breech loading and muzzle loading, together with many other interesting and important inquiries relating to large guns, are now under investigation by a carefully selected tribunal, and the results of that inquiry are looked forward to with great interest.

Water supply and drainage form a branch of engineering which, as affecting sanitary conditions, is now receiving much attention. The address of the late President, Mr. Bateman, having been mainly directed to water supply, it only remains to add that his project for utilising Lake Thirlmere for the supply of Manchester received the sanction of Parliament last session. Important works of drainage and other improvements have been effected in most of the principal cities and towns of the kingdom.

By the action of the City of London, and at a later period of the Metropolitan Board of Works, the condition of the metropolis has been greatly improved and embellished. Old London, Blackfriars, and Westminster bridges, which in 1828 encumbered and obstructed the navigation of the Thames, have been replaced by others affording a much larger water-way. The sewage, which used to be delivered in black streams at intervals along both river fronts, has been intercepted by the great drainage works of Sir Joseph Bazalgette, V.-P., Inst. C.E., who has also carried out the embankment of the river Thames. Under his advice, and that of Colonel Haywood, M. Inst. C.E., numerous street improvements have been made, and in the new buildings bordering on them architects have added very greatly to the embellishment of the metropolis.

If Vauxhall bridge be taken as representing the boundary between London and its suburbs in a westerly direction, there have been three suburban bridges built, namely, the Chelsea, Albert, and Wandsworth bridges.

Eastward of Vauxhall, in what may be considered the active metropolitan area, the only additional public communications opened across the Thames during the last fifty years are the Hungerford Suspension bridge, of Mr. Brunel, V.-P. Inst. C.E., since removed and replaced by the public foot-way in connection with Charing Cross railway bridge, and the Lambeth bridge and the Tower Subway, the two latter constructed by Mr. Peter W. Barlow, M. Inst. C.E.

The extensive increase of traffic, and the general growth of the eastern and more commercial part of the metropolis, produce such difficulties at London bridge, that some other road communication to the eastward of that bridge cannot much longer be delayed.

In the more ordinary operations of building, one of the noticeable changes is in forming foundations by iron cylinders or caissons instead of by cofferdams as formerly used. This newer mode of construction was early employed in railway bridges by Sir William Cubitt, Past-President Inst. C.E., and Sir Charles Fox, M. Inst. C.E. and its most extended and most recent example is found in the great bridge across the Tay.

The use of concrete has largely increased with the improved knowledge of cements. Concrete was formerly employed chiefly in foundations and for the backing of walls; but in the large extension of the Victoria Docks by Mr. A. M. Rendel, M. Inst. C.E., it has been adopted for the entire walls, including the face-work and coping. About 450,000 yards have been used in these works with very successful results.

The employment of gas as a means of illumination, which was only beginning in 1828, has increased in a remarkable degree. The length of gas mains in the metropolis alone was, at the end of 1878, 2,500 miles, for supplying all the private consumers, and there are about 58,000 public lamps for street lighting. Mr. Harry Chubb informs me that in the same year the quantity of coal decarbonised was 1,715,000 tons, which produced nearly 17,500 million cubic feet of gas, besides residual products of the value of £745,000. The coal used appears to be about four-tenths of a ton per annum per head of the population. Of the gross revenue only 5 per cent. is derived from street lighting, while 20 per cent. arises from the sale of residual products, and 75 per cent. from private consumers. The capital invested in gas works in the United Kingdom is £40,000,000, of which about £12,000,000 may be taken to represent the capital of the London Gas Companies.

The application of wrought iron in the superstructure of engineering works commenced with suspension bridges, where the metal is only subjected to tensile action. Its employment in large tubular girders designed to resist rupture by transverse strain, originated with Robert Stephenson, Sir William Fairbairn having carried out the first experiments for him in 1845, and assisted materially with his valuable suggestions. In the tubular bridge at Conway, and in the subsequent larger work over the Menai

Straits, the iron was used in the form of riveted plates, a mode of construction since employed extensively in railway bridges. Before the completion of these works, another step was made in advance, by girders of this metal being framed together in open work. This description of girder involved problems in determining the amount of stress in each member of the structure, which are specially interesting from the exact manner in which the results can be ascertained, and the several parts proportioned to the work they have to perform. It is to these circumstances, and to the greater proportionate depth which can be given to this class of girder, that its economy is attributable.

The improvements effected in the manufacture of steel assume the character of new discoveries, which are tending to revolutionise the iron industries of the world. The Bessemer process, followed by that of Dr. Siemens and Mr. Martin, by producing good steel at a low rate of cost, has displaced a great deal of the iron formerly used in this country—a movement likely to be accelerated by the more recent labours of Mr. I. L. Bell, M. Inst. C.E., and Messrs. Thomas and Gilchrist, in the dephosphoration of the Cleveland ores. Besides the advantages which steel has over iron for rails, wheel tires, and other purposes where it is exposed to wear, and for structural purposes on account of its superior strength, there is a general gain to the community arising from the smaller quantity of coal required for its production. Thus, to make a ton of iron, about 6 tons of coal are necessary, but to make a ton of steel 3 tons of coal suffice; and as it is stated that nearly 50,000,000 tons of coal are annually consumed in iron and steel works, the saving by the substitution of steel for iron has been truly called a "national gain."

The production of modern steel is a subject which I have followed from its commencement with great interest, being early impressed with the importance of introducing a stronger material than wrought iron into engineering structures. Acting as a member of a Committee of Engineers who made an extended series of experiments on steel, the results of which showed conclusively its applicability to structural purposes, and being aware that the consideration of the subject had been frequently urged upon the Government by Sir John Hawkshaw, I took the opportunity of having to make an address to the mechanical section of the British Association at Bradford, to bring the whole matter under notice.[1] The British Association then appointed a committee to

[1] Brit. Assoc. Rep., vol. xliii., 1873. Transactions of the Sections, p. 200.

confer with the Board of Trade, by whom, after much correspondence, the question was referred to Sir John Hawkshaw, Colonel Yolland, R.E., and myself. This resulted in the adoption of a coefficient for steel of 6½ tons to the inch, that of iron being 5 tons, it being further understood that for steel of high qualities the coefficient should be raised by agreement, due precautions being observed in the testing. It would be superfluous to point out to members of this Institution, that in engineering works requiring wide spans, where the weight of the structure is large in proportion to the load to be carried, the economy of employing steel instead of iron will be in a much greater ratio than the relative strength of those metals.

Two great bridges are now in course of construction, one a public road bridge between New York and Brooklyn, designed by Roebling, having one span of 1,595 feet; the other a railway bridge across the Firth of Forth, designed by Sir Thomas Bouch, M. Inst. C.E., which will have two spans, each of 1,600 feet. In both these bridges the employment of steel becomes a necessity, because the weight required to make them in iron would render them impossible.

Although enough is known about steel for ordinary structural purposes, there are properties belonging to that material which greatly need further experimental inquiry. Untempered steel is very like good iron in two of its characteristics. First, it possesses nearly the same modulus of elasticity; and secondly, the force required to extend it to the limit of its elasticity, or the force at which an appreciable permanent set appears, is about half that required to produce rupture. The superior strength of untempered steel over that of good wrought iron is proportionate to the greater range of its elastic action; and the ratio which this greater range of elastic action bears to that of iron varies with different qualities of steel. But the strength of steel may be greatly increased by tempering in oil, a process now much in use. There are no experiments to show whether the increase of strength so obtained is due to a still further increase of the elastic range, or to a change in the modulus of elasticity. Experiments are also wanting to determine what change, if any, arises in the specific gravity of metal when under strain within the limit of its elastic action. This information is essential for the correct computation of the strength of cylinders subjected to internal pressure. Within certain limits the stretching either of iron or of steel, beyond its original elastic limit, increases the strength and the range of elastic action. The process of cold rolling is an example of

this effect. In the Philadelphia Exhibition a large amount of the shafting for driving the machinery was so made. It presents a highly-finished appearance, and is known to increase both the tensile and the transverse resistance.

Steel wire, drawn cold, exhibits remarkable strength. The pianoforte wire used by Sir William Thomson, in his deep-sea soundings, bore 149 tons to the inch, with an elastic range equal to $\frac{1}{86}$ part of its length. The result in this case shows about the same modulus as iron, and an increase of strength proportionate to the increased elastic range. It is probable, however, that in this case, as in some other cases, the increase of strength is accompanied by a great loss of ductility.

The employment of hydraulic machines has largely increased, some being used for producing great pressures and moving great weights, others are made of quicker movement, water motors, applicable to cranes, hoisting apparatus, opening lock gates, and many other purposes. One of the most striking applications of the hydraulic press is that employed by Sir Joseph Whitworth for the compression of molten steel. Those who have witnessed this process will be aware of the enormous difficulties which had to be overcome in subjecting large ingots of molten steel to a pressure amounting to 6 or 7 tons per square inch. The pressure thus obtained is kept up continuously for an hour or more, and completely closes up every air space, gas space or other interstice, and thus renders the ingot perfectly solid and sound. By a further application of the hydraulic press at these works, the use of the hammer is dispensed with in large forgings of steel; the red-hot metal is pressed into its required form by arrangements under easy guidance and control. Forging by hydraulic pressure has at least the appearance of being a far superior process to the rough and noisy hammering which accompanies ordinary forging. It is practised in Prussia, as well as in this country; several specimens of the work were exhibited at the Philadelphia Exhibition of 1876.

The United States Government have recently had constructed a powerful and accurate testing-machine, capable of exerting tensile and compressive strains of 400 tons. This machine has been especially arranged for the investigation of the mechanical properties of steel.

The great advances in practice have been accompanied by a marked extension in an accurate knowledge of the physical sciences; and within the last ten or fifteen years the educational

departments of the country have undergone important changes in this respect. By recent returns issued by the Science and Art Department of the Committee of Council on Education, it appears that the number of schools in which elementary scientific instruction is given has increased in eleven years from 212 to 1,297; that the number of students who came up for examination has increased during the last seven years from 18,750 to 40,086, and that the number of first classes in the elementary and advanced stages has risen in that interval from 2,431 to 11,488.

Mr. Fowler, Past-President Inst. C.E., in his address in 1866, dwelt at some length on the kind of education best suited for an engineer. Of late years, in several of the Universities, Professorships of Engineering have been established, and departments for scientific instruction have been created in different colleges, and the increasing area of scientific requirements renders it desirable that a yet wider field should be given to that class of instruction. It is obvious that pupils should be acquainted with the principles which lie at the foundation of mechanical science, and with the nature and properties of the materials employed, before they can enter with advantage upon actual work, which consists in applying those principles and those materials to practical use. The numerous colleges directed to this class of teaching in France, Germany, and Switzerland, give to the engineers of those countries some advantages in this respect. It is true that the best teaching will be given in vain to those who do not possess the qualities of mind fitted for their avocation; neither will any preliminary education suffice, unless it is accompanied by active observation and subsequent continued self-instruction.

Lord Shaftesbury, in a recent Paper, remarks, that "having given to every one the elements of knowledge, you have given him access to the means of acquiring more"; and he adds, "I am convinced that after all the best education a man gets is that which he gives to himself by his own exertions." There are many instances where power of observation and self-instruction have enabled men to rise without much other teaching. Young men taken from ordinary schools and placed at once as pupils in a workshop or on engineering works, are mainly dependent for their progress on those powers of mind; and what they learn in that way, though laboriously obtained, is rooted and grounded in a manner which probably no other teaching can accomplish. But there can be no doubt that their path would be made easier, and the scope of their observation much wider, by previous education specially directed to the class of subject with which they have to deal. So far as

my experience extends with regard to pupils, those who have come from colleges where applied science is taught, take at once a higher position, and have a much larger sphere of usefulness, than equally clever men who have not had that advantage.

In the early days of the Institution, the knowledge of the strength of materials, and of the laws which govern mechanical action and forces, were very imperfectly understood. There were many theories based on assumed but not always correct data, and many valuable experiments upon which useful but empirical rules had been founded. Smeaton, Telford, Rennie, Tredgold, Beaufoy, and others contributed much to the knowledge existing at that time. My father's essay on the Strength and Stress of Timber appeared in 1817. This book went through many editions under the title of "Barlow's Strength of Materials." It owed its popularity and success to the great want of systematic information which prevailed at that time, and to the fact that besides containing clear mathematical investigations of the several questions, it also gave concise rules for their application, written in simple language such as any well-educated workman could understand. It is curious to observe that until that work appeared, it was still a disputed point whether the deflection of a beam strained transversely varied as the square or as the cube of the length. Bernoulli's investigation gave one result, and Girard's so-called experiments another. My father made a totally independent investigation, accompanied by a series of clear and conclusive experiments, and thus put this question at rest for ever. This fact is one among many which might be cited, showing the necessity of carrying on investigations of this nature, not by theory alone, nor by experiment alone, but by both, so as to check and establish every point of the inquiry.

Professor Rankine, in his address to the Senate of the University of Glasgow in 1855, refers to the antagonism between theory and practice. He attributes its origin to the ancient Greek philosophers, who, in regard to physics and mechanics, entertained the fallacious notion of the existence of a double system of laws; one theoretical, discoverable by contemplation and applicable to celestial bodies, the other mechanical, discoverable by experiment and applicable to terrestrial bodies. And he goes on to show how the science of motion founded by Galileo, and perfected by Newton, overthrew this supposition and proved that celestial and terrestrial mechanics are branches of one science.

That some relics of this antagonism are yet to be found is true. There is a class of practical men who reject the adoption

of any principles except trial and error. But there are others, daily growing in numbers, who are desirous of availing themselves of theoretical knowledge. Among this latter class it is not a question of antagonism, but rather a want of confidence arising from the existence of theories founded on ideal or insufficient data.

There was, for example, a theory of the arch by David Gregory ("Phil. Trans.," 1697), in which it was assumed to be necessary that the line of pressure should coincide with the intrados of the arch. In another by La Hire and Atwood, called the wedge theory, it was supposed that the pressure must be at right angles to the surfaces of the voussoirs. It was not until the subject was taken up by Coulomb, and further elucidated by Professor Moseley, that a theory, based on the conditions existing in a real arch, was established.

Again, in the case of the solid beam strained transversely, Galileo, who, according to history, had his attention drawn to the subject during a visit to the arsenal and dockyards of Venice, promulgated a theory in 1633 assumed to be dependent on pure mathematical principles. This theory, afterwards illustrated by Girard in his "Traité Analytique de la Résistance des Solides," is thus commented upon by my father:—"Nothing can be desired more simple than the results obtained by this theory; but, unfortunately, it is founded on hypotheses, which have nothing equivalent to them in nature."[1] The errors of Galileo's theory were first pointed out by Mariotte, who subjected it to the test of experiment. Then followed Leibnitz, who applied to it Dr. Hooke's law of "ut tensio sic vis," but he restricted it to the action of tension, treating the fibres as incompressible. Bernoulli then took up the question, contending that part of the fibres were compressed and others extended. For some reason, probably because his results did not accord with experiment, he doubted the universal application of Dr. Hooke's law. But this law, which is found to be perfectly consistent with experience, when applied to direct tension or direct compression within the limit of elasticity, is again had recourse to by Dr. Robison, who next follows up the investigation, and by him the subject of the neutral axis is introduced, leaving its position undetermined. This theory of the beam has proved misleading. Tredgold was deceived by it while endeavouring to deduce the tensile strength of cast iron from bars of that metal strained transversely; the

[1] *Vide* "A Treatise on the Strength of Materials." By P. Barlow. New Edition, London, 1867, p. 31.

computed result giving him a tensile strength of 20 tons per inch, whereas it is only 8 tons per inch by experiment. My father, who had ascertained the tensile, compressive, and transverse resistances of wrought iron, was led by this theory into the supposition that the position of the neutral axis rose during strain above the centre of gravity of the section. Subsequent experiments of my own ("Phil. Trans.," 1855), on large rectangular beams of cast iron and wrought iron, proved by actual measurements that the neutral axis was in the centre of gravity of the section, and remained there throughout all the degrees of strain applied.

The subject of the transverse strength of beams has recently been treated by Mr. Charles Emery,[1] of New York, who suggests certain hypotheses which may lead to an amended theory. But there is still no adequate explanation by theorists of those causes which render a solid beam, whether of cast iron, wrought iron, or steel, so much stronger than the present theory of the beam would give it, as deduced from the tensile strengths of those materials.

In looking at the great progress of engineering science during the last half century, it will be observable that some of the most important advances have arisen in this country; among them, the application of steam to locomotion on railways, and in ocean navigation; the employment of wrought iron for ship building and for large girders; the screw propeller, the utilisation of some of the powers of electricity for telegraphs and electric lighting, and the production of modern steel.

But while Englishmen seem to possess in a high degree the power of initiating great and practical ideas, other countries are quick in adopting them, and in many cases improving upon them, so that new applications and adaptations of the greatest value, as well as many new and useful inventions, originate abroad. It is in fact impossible to study the works of foreign engineers without feeling, not only in regard to the magnitude of some of these undertakings, but also to the excellence of their execution and the fertility of resource displayed in overcoming local difficulties, that English engineers have now to deal with competitors with whom it will tax their best energies to keep pace; and in the varied conditions encountered in foreign countries, new and modified methods of treatment arise with which it is desirable that everybody connected with the Institution should be kept informed. It is with this object that the Council, aided by

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lix., p. 329.

their Secretary, Mr. Forrest, have, of late years, added to the Minutes of Proceedings, abstracts of memoirs presented to foreign engineering societies, or printed in technical periodicals abroad. To me it seems of great importance that English engineers, many of whom must look in the future to employment abroad, should be well informed of what is passing in other countries. Much may be done to supply this information by books, and by the perusal of the valuable engineering periodicals of the day. But where practicable, a visit to the engineering works of other countries, and an examination of them considered in reference to the resources available for their execution, and a personal acquaintance and interchange of ideas with the engineers themselves, combine elements of instruction of the greatest value.

Many of the members have the advantage of acquaintance with the more important engineering works in Europe; but there is perhaps no country which presents such varied and extensive information as the United States of America. It became my duty in 1876 to go to America as one of the judges of the Philadelphia Exhibition, and I can not only speak of the great amount of valuable information to be obtained there, but also of the hearty welcome with which English engineers are received by their American brethren. American engineers are in advance of those in this country in regard to the application of steel in engineering structures. In Mr. Eads' great bridge at St. Louis of three arched spans, the centre opening being 520 feet and the side spans nearly as large, the arches are of steel. In a recent large railway bridge,[1] erected at Glasgow, U.S., by General Sooy Smith, the entire structure is of steel. Mr. T. C. Clarke's valuable Paper[2] on large span bridges for railway traffic, read at the Institution during the session 1877–78, shows how carefully the subject of iron openwork girders has of late years been studied and applied in America, and the numerous opportunities which that great country offers for works of that description.

In endeavouring to place on record some of the results of engineering progress during the last fifty years—results which have come more or less under my own observation—I am well aware how much has been omitted. Irrigation, mining, and numerous improvements in machinery, afford ample topics and examples of the general advance.

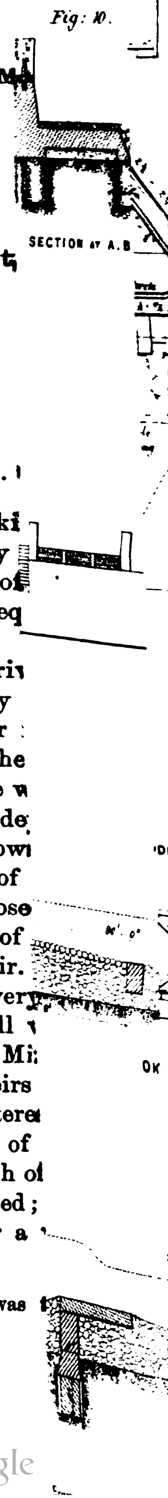
Taking Sir John Hawkshaw's estimate in 1875 as a basis, adding

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lvii., p. 328, and vol. lix. p. 337.
[2] *Ibid.*, vol. liv., p. 179.

the probable cost of steamships, and allowing for the extension of railways, telegraphs, docks, harbours, and other works since that time, the total capital invested in engineering works cannot have been less than 3,500 millions, or about 70 millions annually; of which about $\frac{19}{20}$ appear to belong to railways, steamships, docks, harbours, and telegraphs, all of which are directed to improving and extending the means of transport for passengers and merchandise and the communication of intelligence.

It is observable also that this great progress, which probably exceeds that of any like period in the history of the world, is due to improvements, new applications and discoveries, which are the result of experimental research and greater knowledge of natural laws. Beginning with some ascertained scientific fact, as the power of steam or the transmission of motion by electricity, the advance made by one man becomes the starting point of another; and thus step by step the point now reached has been arrived at, and will soon be passed by further developments in the future. Thus neither railways, telegraphs, steam navigation, nor other achievements, in their present advanced form, can be assigned to the credit of any one man, but they represent the cumulative result of the genius and perseverance of numerous individuals. The Institution is justified in regarding with satisfaction the number of contributors to this advance to be found among its past and present members.

In conclusion, I desire to acknowledge and to express the indebtedness all must feel to those men, both within and without the profession, in foreign countries as well as in this, who by study and experimental research are continually adding to an exact knowledge of the great sources of power in Nature—that power, the direction of which to the use and convenience of man, constitutes the fundamental element in the Charter of THE INSTITUTION OF CIVIL ENGINEERS.



20 January, 1880.

WILLIAM HENRY BARLOW, F.R.S., President, in the Chair.

(*Paper No. 1655.*)

"Fixed and Movable Weirs."[1]

By Leveson Francis Vernon-Harcourt, M.A., M. Inst.

The Author proposes to refer briefly to the various ki weirs which are either permanently fixed or only partially able, and to describe at greater length the different types of which can be wholly removed in time of flood, and are conseq termed movable weirs.

Weirs are employed for raising the water-level of a ri navigation, for irrigation, or for mills. Locks are usually in a direct artificial cut where the river makes a bend, or smaller channel where the river is divided into two branche the original or larger channel is closed by a weir. The w raised to the height necessary for maintaining a sufficient de water for the navigation, and the discharge of the river flow the weir. This kind of weir may be termed for the sake of ness an overfall weir. The larger overfall weirs are compose bank of rubble stone protected by pitching, with a row of piling along the sill and along the lower foot of the weir. up-stream slope is steep, and the down-stream slope very (Plate 1, Fig. 1). Descriptions and drawings of overfall w constructed across the river Severn, are given in the Mi of Proceedings for the years 1846[2] and 1860.[3] These weirs placed obliquely to the course of the stream, and interes discussions took place on this subject after the reading of Paper. The oblique position was chosen so that the length of overfall, and consequently the discharge, might be increased; it is evident that an advantage is thereby gained over a

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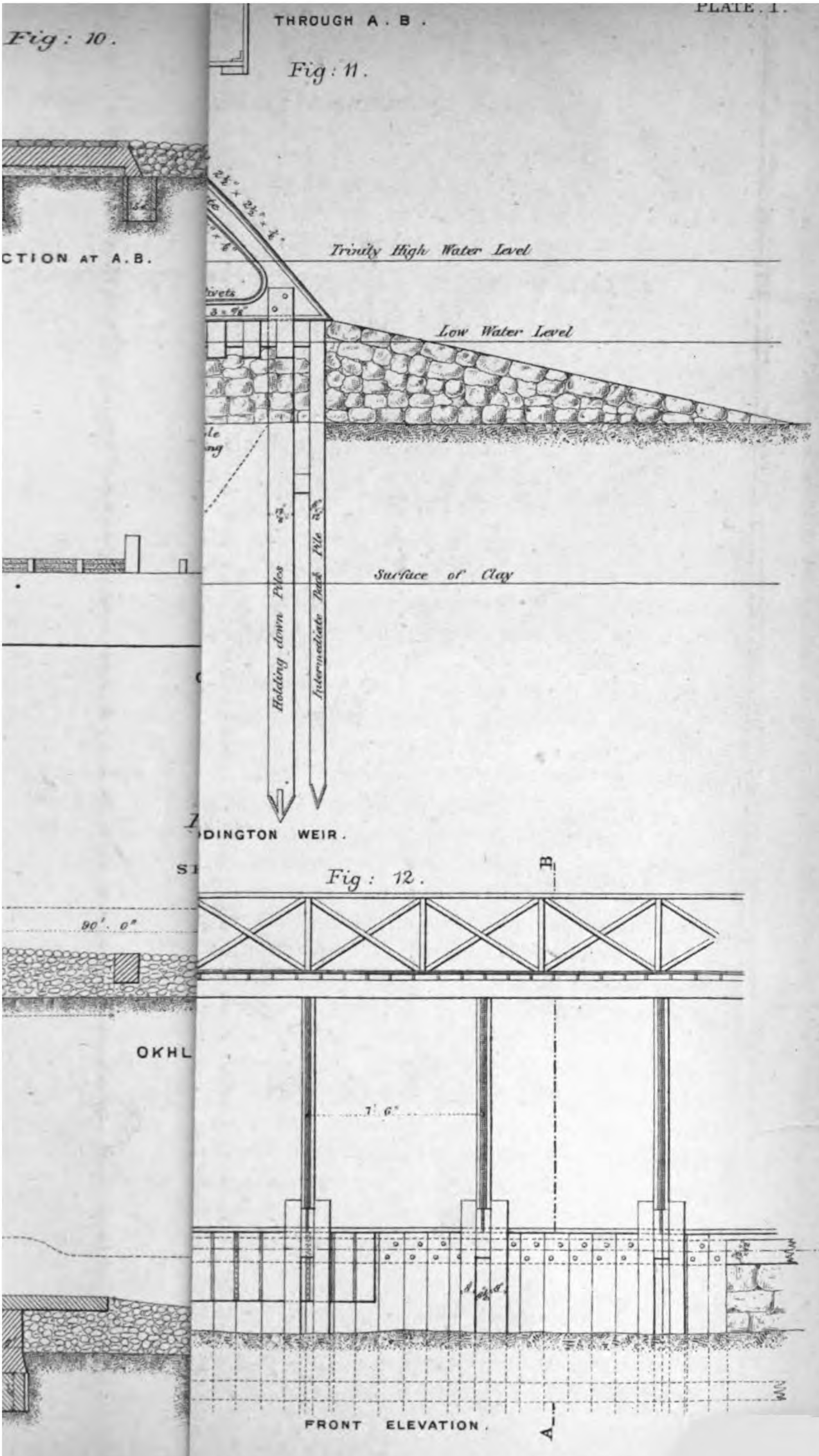
[1] The discussion upon this and upon the succeeding Paper was t together.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. v., p. 340.

[3] *Ibid.*, vol. xix., p. 527.



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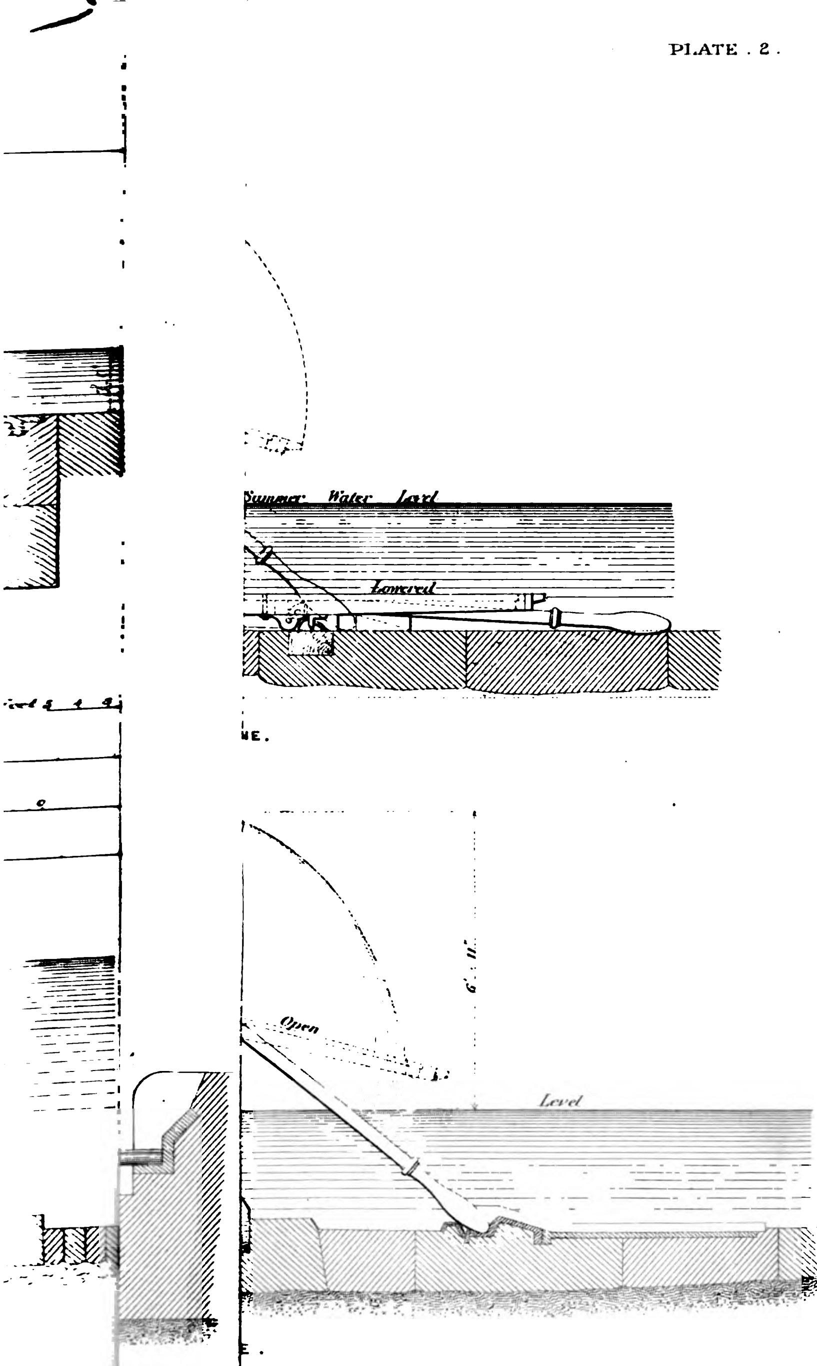

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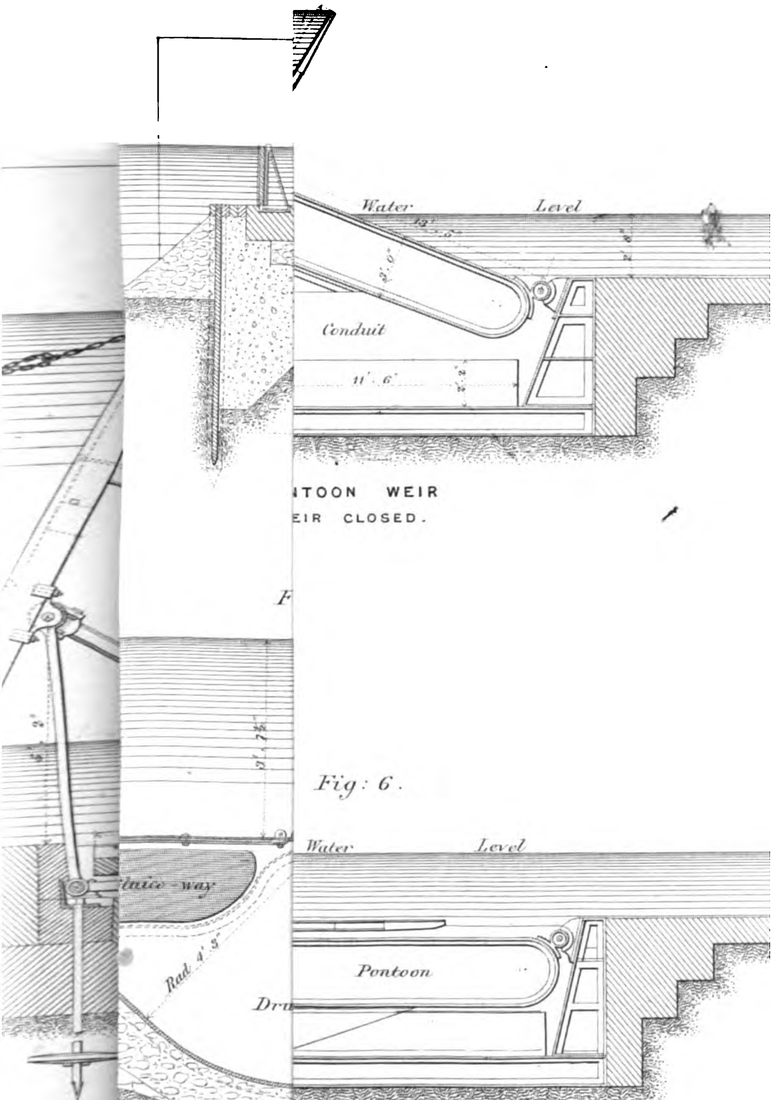
Fig : 5.



ITOON WEIR

EIR CLOSED.

IS WEI

PASS.

WEIR OPEN.

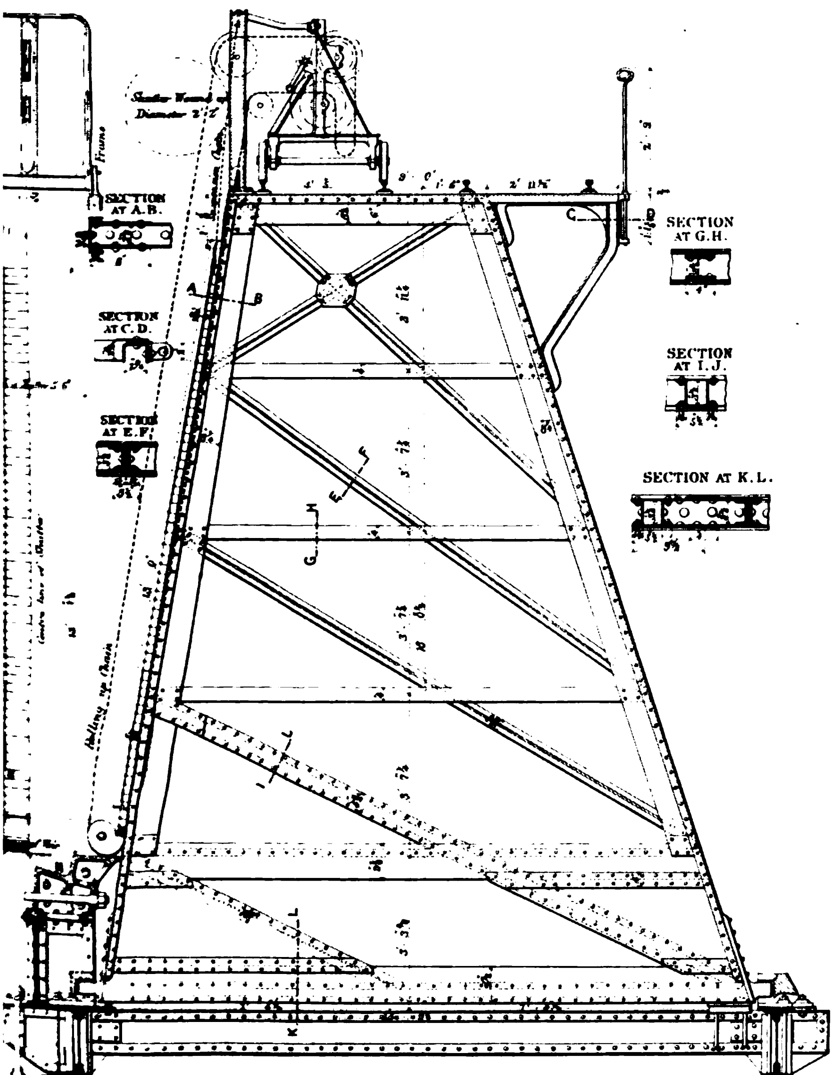
THOS KELL, LITH. 40 KING St COVENT GARDEN

MOVABLE WEIRS.

FRAME ACROSS NAVIGABLE PASS AT PORT VILLEZ WEIR.

[...] ELEVATION [...] OPENING.

SIDE ELEVATION.



Note. The arrangement at N was designed for supporting the ends of the Needles with which it was originally proposed to close the Weir.

Scale for Elevation.

Inches 12 9 6 3 0 1 2 3 4 5 Feet

Scale for Details.

Inches 12 9 6 3 0 1 2 Feet

placed directly across the stream, especially when the velocity of approach is small; but the merit claimed for these weirs, of actually increasing the rate of discharge, and diminishing damage from floods, is inadmissible. The tendency of oblique weirs, like those referred to, is to divert the strongest stream, and consequently the deepest channel, towards the bank on which the upper end of the oblique weir is situated. The sills of overfall weirs are accordingly sometimes formed of two straight lines which make an angle in the centre pointing up stream, or in a curved line convex on the up-stream side (Plate 1, Figs. 2 and 3). These forms, whilst retaining the advantage of an oblique weir, direct the stream into a central channel. When a lock is situated in the same channel as the weir it has been found advantageous, for the purpose of diminishing eddies and back currents near the lock, to join the side wall of the lock with the oblique weir, starting from the opposite bank, by a short length of weir placed at right angles to the stream. This plan has answered perfectly at some locks on the river Lot, in France [1] (Plate 1, Figs. 4 and 5).

Where the drainage area above the weir is extensive and the fall of the river bed small, an additional outlet has to be provided for the flood waters. This is usually effected by erecting a draw-door weir across a portion of the channel. A draw-door weir is generally constructed of a row of piles driven at regular intervals, the spaces between them being closed by wooden panels which slide down grooves at the sides of the piles, and can be drawn up when required. A fine example of this type of weir was erected across the Thames, at Teddington, in 1872 (Plate 1, Figs. 11, 12, and 13). The weir is placed in a straight line very obliquely to the river; it is divided into four separate bays, and has a total length of 480 feet. Along the three down-stream bays wrought-iron frames are placed at regular intervals. The two central bays, 172 feet 6 inches and 69 feet 9 inches in width, are closed by large draw-doors, which are 6 feet high and 7 feet 4 inches wide, in the up-stream bay, formed of plate iron strengthened with angle irons, which slide in vertical grooves at the sides of the frames. The frames carry a foot-bridge; on this there is a tramroad on which a crab runs for lifting the draw-doors. This weir was designed by Mr. Leach, M. Inst. C.E.

In small mill streams an overflow weir is generally placed across the bank where the mill stream and the old channel separate; and a draw-door weir is erected in the bank a short distance above the

[1] *Vide* "Annales des Ponts et Chaussées," 4th series, vol. ix., 1865, p. 160.

mill-gate, to carry off the excess of water when the mill-gate is closed or the river is in flood.

Weirs placed across rivers, for preserving and diverting the water for irrigation, resemble overfall weirs. They retain the water during the dry season, and when the river is in flood it flows over the weir. In India, the natives in former times used to make temporary dams of sand or loose stones, which served to keep back the water when the river was low, and were washed away in the rainy season, so that the work had to be repeated each year. In recent years these weirs, or anicuts as they are termed, have been made more durable (Plate 1, Figs. 6, 7, and 8). They are generally constructed of dry rubble, concrete, or rubble stone set in cement, protected on the face by pitching or ashlar set in cement. The up-stream side of the anicut is nearly vertical, and the down-stream side has a flat slope terminated at the base by a stone apron, laid on the river bed, to prevent scour. The foundations depend on the nature of the bed, but usually cross walls of masonry along each foot, and sometimes down the centre, carried to some depth below the bed of the river, protect the anicut from being undermined. Sluices are provided at the sides for discharging any excess of water, and for removing silt. Some of these anicuts are of great length. The Godavery anicut, consisting of a masonry dam 12 feet high, and crossing four separate branches of the river, has a total length of nearly 2½ miles; and the Dehree anicut of the Sone canals, composed chiefly of dry rubble, with three cross walls of masonry, and 8 feet in height, is 2½ miles long. The Okhla anicut is an instance where the foundations of the cross walls have not been carried down lower than the rest of the embankment. Cross sections of some of the principal anicuts erected in India are given in the "Professional Papers on Indian Engineering;"[1] and descriptions of these works are furnished both in the above publication and in a report, made in 1853, on "The Irrigation Works of the Madras Presidency," by the late Colonel Baird Smith; and also in the Minutes of Proceedings for 1867–8,[2] where irrigation weirs erected in Spain are described.[3]

Some of the irrigation weirs in Northern India, instead of forming a continuous embankment, are built with piers having openings between them of about 10 feet, and the spaces are

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[1] *Vide* "Professional Papers on Indian Engineering," 2nd series, vol. vi., p. 239, plate xxx.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvii., pp. 454–471.

[3] *Ibid.*, vol. xxvii., p. 483.

closed by planks sliding down grooves formed in the sides of the piers. The piers rest on a masonry flooring carried across the river; and the two ends of the weir are built solid for a certain distance from each bank. The openings are sometimes closed by gates turning on a horizontal axis at the level of the flooring, and held up by chains.[1] These open weirs are called dams, and somewhat resemble draw-door weirs on a large scale, or M. Thénard's form of movable shutter weir hereafter described. Dams are generally less costly than anicuts; they interfere less with the normal flow of the river, and prevent the accumulation of silt above the weir.

Waste weirs, known in India as calingulahs, are constructed at the ends of embankments, or bunds, carried across valleys for forming tanks, or reservoirs, for the purposes of irrigation. A calingulah consists of a wall of rubble masonry into which upright stones are fixed at the top about 3 feet apart (Plate 1, Figs. 9 and 10). The spaces between these upright stones are closed with timber, straw, turf, or rubbish to increase the capacity of the tank when the flow of water is small; and when a flood is expected, the obstructions are removed to afford an outlet for the surplus water.

Draw-door weirs, according to the Author's experience, have their sills placed considerably above the bed of the stream, greatly reducing the waterway; and this is still further contracted by the upright posts between which the draw-doors slide.

Movable weirs have been devised to remedy these defects in the ordinary draw-door weir; to hold up the water at a higher level in summer, for the purposes of navigation, where the erection of a lock is not considered advisable; also, where a lock exists, to enable the navigation to be conducted intermittently, in very dry weather, by flushing, known in France under the term "éclusée." Flushing consists in producing a temporary artificial flood by the sudden opening of the weir, by which a convoy of boats, collected above the weir, are floated over the shallows below. A movable weir is, in fact, a barrier placed across a river for maintaining the water above it at any desired height in summer, and capable of being entirely removed, so as to present no obstruction to the waterway in time of flood. The only form of movable weir in England,

[1] A description of these weirs and of the ingenious modifications by Mr. Fouracres is given by Lieut.-General Rundall in a course of lectures on "Irrigation Works in India," at Chatham in 1875.

with which the Author is acquainted, is the type which may be seen on the Upper Thames above Oxford, where long square wooden upright bars, called rimers, resting between wooden sills and walings, serve to keep in place a series of boards, or paddles, fastened to the ends of poles, which can be raised or lowered successively by one man. The rimers and paddles are heavy to lift, and the sills are considerably above the bed of the river.

No description of any of the various kinds of movable weirs has hitherto been brought forward for discussion at the Institution. Brief accounts of such works have been given in the Abstracts[1] appended to the Minutes of Proceedings; and the subject has also been alluded to in a Paper on "The Eastern Canal of France,"[2] and in a Paper by the Author "On the Progress of Public Works Engineering in Foreign Countries."[3] A Report by Mr. W. Forsyth, and another by Mr. R. Manning, M. Inst. C.E., to the Board of Public Works in Dublin, in 1873, "On the Construction and Working of the Barrages of the Seine, Marne, and Yonne, and their Applicability to the Circumstances of the River Shannon," and a Paper by Dr. Pearson, "On a new kind of Self-Acting Weir recently introduced on the Rivers of France and Belgium," read at a meeting of the Cambridge Philosophical Society in 1878,[4] are, so far as the Author is aware, the only English publications treating of the subject.[5] The Author hopes that the present Paper may in some measure supply this deficiency.

Five different types of movable weirs have been erected abroad: 1. The bear trap. 2. Frame or needle weir. (Barrage à Fermettes, ou Barrage à Aiguilles). 3. Movable shutter weir. (Barrage à hausses mobiles.) 4. Drum weir. (Barrage à Tambour.) 5. Pontoon weir. (Barrage à Ponton.)

The first real type of movable weir was erected in the United States. But the credit of improving on the original rough type, of devising new types, and of rendering them generally applicable to the requirements of navigation, belongs to the French, who have introduced them extensively on several rivers.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliv., p. 268; vol. l., p. 216; vol. liv., pp. 297 and 300.

[2] *Ibid.*, vol. lv., p. 229.

[3] *Ibid.*, vol. lv., p. 283.

[4] *Vide* "Proceedings of the Cambridge Philosophical Society," vol. iii., part iv., p. 138.

[5] Since this Paper was written, the Author has found that a Paper on "River Dams or Weirs in France," by Lieutenant Heywood, was published in the "Professional Papers on Indian Engineering," vol. vii., 1870, No. 1A; and General Rundall's lectures, already referred to, should be added to this list.

1. The Bear Trap.

A movable weir called by this name was erected, in 1818, by Josiah White, on the Lehigh river, Pennsylvania.[1] It consisted of two gates, turning on horizontal axes at the bottom, the up-stream gate pointing down stream, and the down-stream gate pointing up stream. The upper end of the up-stream gate, when raised, was supported on the top edge of the down-stream gate. When the water was withdrawn from beneath the gates, the down-stream gate fell flat down, and the up-stream gate, being no longer supported, fell on the down-stream gate.[2] This first example of a movable dam has disappeared, and, according to M. Malézieux,[3] its existence has been almost forgotten in America. The system has, however, been reproduced in France, with some improvements, at the weir of Laneuville-au-Pont, on the Marne.[4] This weir is shown on Plate 2, Fig. 1. The passage is 29 feet 6 inches wide. There are culverts in the side walls which connect the upper and lower pools, and also communicate by a side passage with the space under the gates. When it is desired to close the gates, the pressure of the water flowing in from above is temporarily removed by closing a movable shutter weir placed on the up-stream side of the gates. The lower sluice gates of the culverts are closed, and the upper ones are opened, which causes the water to rush under the gates and raise them to the required height, where they remain fixed by suitable arrangements. The water continues to rise, filling the space between the upper gate and the movable shutter weir, till the level of the water on both sides of the shutter weir is the same, when the shutter, being relieved of the pressure on its upper side, and being hinged to the apron, falls down flat upon it. To open the gates it is only necessary to close the upper sluice gates of the culverts, and to open the lower ones, when the water under the gates, being shut off from the upper pool, flows down into the lower pool through the culverts, and the gates fall down. For closing

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[1] *Vide* "Engineering News Chicago," vol. iv., p. 141; and "Histoire et Description des Voies de Communication aux États-Unis." Michel Chevalier, vol. ii., p. 464.

[2] This type of weir is referred to by M. Cordier in his work published in 1828, "Essais sur la construction des Routes des Canaux et la Législation des Travaux Publics," vol. ii., p. cxxiii., in which he states that he had constructed similar ones in the Department du Nord.

[3] *Vide* "Travaux Publics des États-Unis d'Amérique," Malézieux, p. 280.

[4] *Vide* "Annales des Ponts et Chaussées," 3rd series, vol. vi., 1853, p. 252; and "Portefeuille de l'École des Ponts et Chaussées," 1858, part ii., p. 214.

the gates it is necessary to have a head of 2 feet of water, and the time required for closing the gates depends on the time taken by the upper water in rising to this head after the shutter and lower sluice gates have been closed. The operation of opening occupies three minutes. The gates, according to this system, are not counterbalanced, and the friction at the heel-posts is considerable. The weir at Laneuville cost £2,864.

2. Frame, or Needle Weir.[1]

This system consists of a series of wrought-iron frames, placed parallel to the current, turning on hinges fixed to the apron, and connected and secured when standing upright by movable horizontal iron bars. Wooden spars or needles (*aiguilles*), resting against the sill at the bottom and against the horizontal bars at the top, form the dam which keeps up the water (Plate 2, Fig. 3). Each frame is in the form of a trapezium; the bottom horizontal piece has iron pins at its extremities, turning in cast-iron sockets. The horizontal piece at the top serves to support a footway made with planks. The up-stream side is vertical, and the down-stream side is battered. The whole frame is strengthened by braces in proportion to its height. The frames are placed at intervals of about 3 or 4 feet, so that they may not be too heavy to be raised or lowered by the man in charge. The needles are removed by hand, one by one, when the weir is to be opened. The movable bars are drawn aside and the frames are lowered by means of chains attached to them; the frames fall over one another into a recess in the apron, and leave the passage unobstructed. When the weir is to be closed, the frames are pulled up successively by the chains attached to them, the connecting bars are fastened to each pair of frames, and lastly, the needles are placed, one by one, in position.

The first weir of this type was erected by MM. Poirée and Chanoine, in 1834, at Basseville, on the river Yonne. The second was put up at Decise, on the Loire, in 1836. In 1838 a similar weir was erected at Épineau, on the Yonne, of which a description has been published by M. Chanoine.[2] The work was commenced in June and completed in September. The wooden needles were 2¾ inches by 1½ inch, and 8 feet long, and the weight of each

[1] *Vide* "Cours de Navigation Intérieure," de Lagrené, vol. iii., p. 174.

[2] *Vide* "Annales des Ponts et Chaussées," 1st series, vol. xvii., 1839, p. 238.

was 13 lbs. Each frame was made of bar iron, 1½ inch square, forming a trapezium 7 feet high, 4 feet 7 inches wide at the base, and 4 feet 3 inches at the top. The frames were placed 3¼ feet apart. The length of the weir was 230 feet, and its height above the sill 6½ feet. The weir cost £25 per lineal foot. Two men were employed in working the weir. The average time occupied in removing a lineal yard of the weir was two minutes twenty-one seconds. Boats could descend when about 65 lineal feet of weir were opened, and ascend when about 50 feet were open.

Several similar weirs were subsequently erected on the Yonne,[1] but the distance between each frame was increased to 3 feet 7 inches, and they were made 7 feet 4½ inches high. Both M. Poirée and M. Chanoine devised methods for the rapid release of the needles mechanically,[2] instead of raising each needle by hand, which enabled a weir, 130 feet in length, to be opened in fifteen minutes, instead of at least an hour according to the primitive arrangements.

In order to prevent the constant recurrence of injury from floods occasioned by fixed weirs on the Saône, movable needle weirs were erected on that river between 1840 and 1845.[3] These weirs were not erected, like those previously mentioned, for the purposes of navigation, but solely to afford a free passage along a side channel for the flood waters. Needle weirs have also been erected on the Seine, the Marne, the Meuse, the Oise, the Cher, and the Allier.[4] By the adoption of a contrivance for releasing the needles, the necessity for an overfall was dispensed with, and the height of the frames was increased up to 11 feet at the Martot weir.

Various objections have been made to this form of weir:[5] (1.) The needles do not form a water-tight barrier. (2.) Their removal and replacement is laborious, and at times dangerous. (3.) They are liable to break and to be lost. (4.) When the water rises above the foot-bridge they cannot be removed; an instance of this occurred at Suresnes in 1873.

Several expedients have been resorted to for remedying the first defect, such as stopping the interstices between the needles with hay, putting a second row of needles as covers at the front, or

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[1] *Vide* "Annales des Ponts et Chaussées," 5th series, vol. v., 1873, p. 177.

[2] *Ibid.*, 2nd series, vol. v., 1843, p. 241, and p. 264.

[3] *Ibid.*, 3rd series, vol. ix., 1845, p. 10.

[4] *Ibid.*, 4th series, vol. xi., 1866, p. 172; vol. xiii., 1867, p. 135; and 5th series, vol. vii., 1874, p. 659.

[5] *Ibid.*, 4th series, vol. xi., 1866, p. 180; vol. xv., 1868, p. 285; vol. xvi., 1868, p. 50; and vol. xx., 1870, p. 425.

stretching a sort of curtain of canvas across the upper face of the needles. The second objection has been met by using a boat for removing the needles; or by the releasing gear referred to above, and making the foot-bridge 3 feet instead of 2 feet wide. The size of the needles has been increased, and by attaching each of them to a rope fastened to the frames, or ashore, they are readily recovered when released from the weir. One means of preventing the sudden submergence of the weir when closed is the establishment of an overfall, which always formed an adjunct to the earlier needle weirs; but an overfall is objectionable, both on account of its cost, and also because, when low enough to be thoroughly efficient, it tends to reduce the level of the upper water below the height to which the weir can retain it. Another remedy is to raise the foot-bridge, but this necessitates increasing the length, and consequently the weight, of the needles. However, ordinary care, with timely warning of a flood, should suffice to prevent the occurrence of this kind of mishap. As the needles have to be increased in thickness, as well as in length, when the head of water to be retained is greater, the weight of the needles increases rapidly with an increase in the height of the weir. Now, although the needles can be released mechanically, they can only be replaced by hand; so the height to which such a weir could be carried is limited by the necessity of its being closed by needles not too heavy for a man to manage. This has, accordingly, led to the endeavour to substitute some barrier instead of the needles in the movable frame weirs, which is not so limited in its application. At the weir of Notre-Dame-de-la-Garenne, the height of which is 8½ feet, the needles in some of the openings have been replaced by a sort of shutter, formed of a series of narrow horizontal boards, joined by hinges, and decreasing in thickness towards the top, which slides between the flanges of the front T-iron of the frames, and can be rolled up when the weir is to be opened.[1] This method is to be employed for closing the large new frame weir in course of construction at Port-Villez, according to the designs of M. Caméré (Plate 4). Another plan, proposed by M. Boulé, and successfully tried at the Port-à-l'Anglais weir,[2] was recommended for adoption at Port-Villez. In the place of the needles of M. Poirée's system, a series of boards, placed horizontally, sliding between the movable frames, is employed. They can be raised,

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[1] *Vide* "Notices sur les Modèles, Cartes et Dessins relatifs aux Travaux des Ponts et Chaussées. Exposition Universelle à Paris," 1878, p. 121.

[2] *Vide* "Annales des Ponts et Chaussées," 5th series, vol. xi., 1876, p. 320.

one after another, by a crab placed on the foot-bridge. As the boards are removed in rows there is never a great fall of water above them, and consequently the lifting of the boards can be easily managed. The boards can be varied in thickness according to the head of water which they are required to support; and the foot-bridge can be raised above all danger of submergence. These modifications remove the most important objections to the movable frame weir, and enable the system to be adopted for greater heights than is possible with needles.

3. Movable Shutter Weir.[1]

A gate, turning on a horizontal axis at the bottom, supported by a prop when raised for retaining a head of water, and falling flat on the apron when the prop is drawn aside, appears to have been used in the last century across an overfall on the river Orb.[2] M. Thénard erected movable dams across three overfalls on the river Isle, between 1832 and 1837, similar in principle to the one on the Orb, but having a second gate, placed above the dam, turning on a horizontal axis at the bottom and designed to fall flat, when opened, on its up-stream side.[3] When the dam was to be raised the upper gates were lifted, and stopping any flow of water over the overfall, enabled the weir-keeper to raise the lower gates. The level of the water on each side of the upper gates was next equalised by opening valves in these gates, which could then be lowered. M. Thénard erected seven larger gates (5 feet 7 inches high and 3 feet 11 inches wide) at the St. Antoine weir, in 1843, with a narrow footway along the top of the upper gates, from which the weir-keeper could raise the lower gates. This sort of movable weir, though only used on overfalls, resembles somewhat in principle the Bear Trap already described, the prop taking the place of the second gate. M. Thénard intended to modify and extend his system; but having retired, and being succeeded by M. Chanoine, the scheme was not carried out. M. Chanoine erected a weir at Courbeton, completed in 1850, which was a combination of the systems of M. Poirée and M. Thénard, the needle dam of M. Poirée taking the place of the upper gate in M. Thénard's system.[4] This kind of weir was, however, only suitable for small heights, such as are needed on overfalls. M. Girard devised a method of raising

[1] *Vide* "Cours de Navigation Intérieure," de Lagrené, vol. iii., p. 212.

[2] *Vide* "Traité des Travaux de Navigation," Delalande, 1778, p. 66.

[3] *Vide* "Annales des Ponts et Chaussées," 2nd series, vol, ii., 1841, p. 45; and 3rd series, vol. ii., 1851, p. 140.

[4] *Ibid.*, 3rd series, vol. ii., 1851, p. 160.

the gates of this type of weir, by using an hydraulic press placed below and connected to the centre of the underside of the gate. The press is supplied from an accumulator on the bank, the water being pumped into the accumulator by a turbine, turned by the fall of water at the weir. This contrivance was tried at the overfall of Brûlée Island weir[1] (Plate 2, Fig. 2).

To obtain a system suitable for navigable passes a considerable modification of M. Thénard's design was needed. This was accomplished by M. Chanoine in 1852,[2] and carried into execution at the weir he erected at Conflans-sur-Seine. He first applied the term "hausses à bascule" (tumbling shutters) to his invention, which at overfalls were made self-acting; and subsequently the general term "barrage à hausses mobiles" (movable shutter weir) was given to this system, by which M. Thénard's had been previously designated.

M. Chanoine's system (Plate 2, Figs. 4, 5) consists of a gate or shutter, turning on an axis on its down-stream side, supported on the top of a wrought-iron tressel, resting on and hinged to the apron of the weir.[3] The axis on which the shutter revolves is situated at a distance of from one-third to one-half of the height of the gate from the bottom. When the trestle is raised to an upright position and the shutter is closed, the shutter has a slight inclination of about one-eighth of its length down stream at the top, and abuts at the bottom against a projecting sill of the apron, being supported in that position by a strong wrought-iron prop fastened between two flanges projecting from the top of the tressel by a bolt, on which it turns. The prop, when supporting the shutter, is inclined at an angle of about 45° to the horizontal, and its lower end rests in a cast-iron shoe, from which it can be released by a sideways pull, produced by a bar with projections, "barre a talon" (tripping bar), laid across the apron and worked from each bank. When the prop is released it slides down in a groove along the apron, and the trestle and shutter, being unsupported, fall flat into a recess in the apron. The shutter is raised by a chain attached to its lower edge, wound up by a crab placed in a barge or on a foot-bridge. The shutter is kept in a horizontal position whilst being raised; as soon as the trestle is upright, and the prop in position, the shutter can be allowed to close under the pressure of the water, or, if necessary, is pulled up by a chain attached to its top. A

[1] *Vide* "Annales des Ponts et Chaussées," 5th series, vol. vi., 1873, p. 360; and "Cours de Navigation Intérieure," de Lagrené, vol. iii., p. 352.

[2] *Ibid.*, 3rd series, vol. x., 1855, p. 97.

[3] *Ibid.*, 4th series, vol. ii., 1861, p. 209.

weir on this system consists of two parts, namely, a navigable pass and a self-acting overfall weir. The navigable pass, the sill of which should be level with the bed of the river above the weir, is, for the sake of economy, made merely of sufficient width to accommodate the navigation. On the Upper Seine the sills of the overfall weirs are placed 1 foot 8 inches above the summer water level; the widths of the navigable passes vary from 130 feet to 180 feet, and the widths of the overfalls from 200 feet to 230 feet. The position of the axis on which a shutter of the navigable pass turns is fixed so that the hydrostatic pressure on the upper portion is always less than on the lower portion; whereas, for an overfall shutter the axis is so placed that, when the water rises to a certain height above the weir, the pressure on the portion above the axis overcomes the pressure on the lower portion and the shutter opens, assuming a horizontal position till the lowering of the water reverses the balance of pressure, and causes the shutter to close (Plate 3, Fig. 2).

The first weir of this type, erected at Conflans-sur-Seine,[1] and completed in 1858, has a navigable pass 114½ feet wide, and an overfall 85 feet wide. There are twenty-nine shutters across the navigable pass, each 7 feet 9 inches high and 3 feet 7 inches wide; and twenty shutters across the overfall, each 4 feet 4½ inches high and 3 feet 11 inches wide. The cost of the works amounted to £2,850. The time required for opening the navigable pass is three minutes, and for closing, on the average, one hour and eight minutes, the shortest time being forty-five minutes, and the longest an hour and a half. The closing was performed by a winch, for working the chains, placed on a barge securely moored above the weir. The self-acting shutters of the overfall, when opened, are not generally lowered flat on to the apron, so that they can be readily closed by the weir-keeper, if it is advisable to shut them before the water has lowered sufficiently for them to close of themselves. The working of this weir was considered so satisfactory, that it was decided to adopt the same type for the twenty-nine new weirs to be erected for increasing the navigable depth of the Seine and Yonne between Laroche and Paris.[2] Similar weirs were erected about the same time for the navigation passes on the Marne, but a foot-bridge, carried on movable frames, was substituted for the barge to carry the crab for closing the shutters.[3] This alteration

[1] *Vide* "Annales des Ponts et Chaussées," 3rd series, vol. xviii., 1859, p. 197.
[2] *Ibid.*, 4th series, vol. xi., 1866, p. 180; and 5th series, vol. v., 1873, p. 177.
[3] *Ibid.*, 4th series, vol. xi., 1866, p. 188.

was found so desirable that it has since been introduced at most of the movable shutter weirs, and it formed part of the original design for the navigable pass constructed in 1870 at Port-à-l'Anglais, where M. Chanoine's system has been carried out on a large scale.[1] (Plate 3, Fig. 1.) A movable shutter weir and a lock adjoining were constructed in 1863–4. In 1869 it became necessary to provide a larger navigation pass during the execution of some works at the lock. A channel was cut, about 115 feet in width, through the overfall weir, and movable shutters were placed across the channel, capable of retaining a height of 13½ feet of water above the sill. The shutters across the original pass, which were 9 feet 10 inches high, had a width of 3 feet 11 inches, but in consequence of the increased depth of the new pass the width of the shutters across it was reduced to 3½ feet. The foot-bridge was placed on frames, 15 feet 9 inches high, similar to those used at the needle weirs; and a crab, running along a tramway on the foot-bridge, was employed for working the chains attached to the shutters; and the opening and closing of the pass has been performed in a perfectly satisfactory manner. The cost per lineal foot of this weir, as given by M. Boulé, is £62 16*s.*; but adding the cost of the foot-bridge, it amounts to £67 12*s.* M. Cambuzat has raised some objections to this system of weir, such as the liability of the tripping bar to be broken by stones or other obstacles getting into the grooves, preventing the lowering of the shutter, the occasional breaking of the trestles from repeated falls on the apron, and the scour which a sudden opening of the shutters produces.[2]

Weirs very similar in principle are being erected on the Kanawha river in America. The only difference between these weirs and M. Chanoine's consists in the employment of an iron frame, enclosing the movable shutter or wicket, in the place of the trestles. The wickets in the movable weir erected at Brownstoun, 8 miles above Charleston, are 13 feet 6 inches high, and 3 feet 8 inches wide.

4. Drum Weir.

This type of weir, invented by M. Desfontaines, consists of an upper and a lower paddle, capable of making a quarter of a revolution round a horizontal axis between them.[3] (Plate 3, Figs. 3 and 4.) The upper paddle, when upright, forms the weir, and

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[1] *Vide* "Annales des Ponts et Chaussées," 5th series, vol. vi., 1873, p. 98.

[2] *Ibid.*, 4th series, vol. xiii., 1867, p. 135.

[3] *Ibid.*, 4th series, vol. xi., 1866, p. 190; and "Cours de Navigation Intérieure," de Lagrené, vol. iii., p. 295.

the lower one, which may be made with advantage slightly the larger, is sunk in a closed recess below the apron, in the form of a quarter of a cylinder, in which it revolves, and from which the name "drum" is derived. The weir is worked by the action of the water on the lower paddle, by letting in water from the upper pool, through sluices, into the drum above or below the lower paddle, according as the weir is to be closed or opened; and the water on the opposite side of the paddle escapes into the lower pool through sluices, the communication of which with the upper pool is cut off. When the weir is closed, both paddles are vertical, and when open they lie horizontally, the lower one being at the level of the bottom of the upper sluiceway, and consequently at a lower level than the upper paddle, which lies flat on the apron at the top of the drum. Owing to the space below the sill of the weir required for the lower paddle, this system is only suitable for overfall weirs. The first weirs of this kind were erected by M. Desfontaines at Damery weir, on the Marne, in 1857, and at Courcelles weir in 1861. Between 1861 and 1867 this principle was adopted at the overfalls of nine weirs on the Marne. The drum, which had an iron casing in the first two instances, was subsequently walled round with masonry. A detailed description of one of these weirs, erected at Joinville in 1867, is furnished by M. Malézieux.[1] There are forty-two sets of paddles, 3 feet 7 inches high, and 4 feet 8 inches wide. To control the extent of the opening of the weir, M. Desfontaines hinged a sort of iron crutch to the lower side of the upper paddle. By means of a notched bar, placed across the apron below the weir, and capable of being moved up or down stream, the foot of the crutch can be arrested at any point when sliding down the apron during the lowering of the upper paddle, and the extent of the revolution of the paddle can thus be regulated. M. Desfontaines has since attained the same object without the use of these crutches, by introducing sluices at both abutments of the overfall. By opening or closing each of these sluices more or less, at one side or the other, one or more of the paddles can be raised or lowered, and thus any desired discharge can be obtained over the overfall. The whole process of opening or closing the weir consists in raising or lowering a sluice-gate, and consequently it might be possible to render this weir automatic, by connecting the sluice-gate with a float on the upper water. Gratings in front of the sluiceways prevent stones or rubbish washed down by the river from getting into the drums,

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[1] *Vide* "Annales des Ponts et Chaussées," 4th series, vol. xvi., 1868, p. 482.

and the abundant scour provided by the sluices keeps the drums clear of mud. The objections stated against this system are, that the masonry and ironwork require to be carefully executed, and that it is difficult to obtain a greater height than 3½ feet, on account of the depth below the sill to which the drum foundations have to be carried, which would also lead to difficulties in repairs.

5. Pontoon Weir.

M. Krantz, the inventor of this system of movable weir, states at the outset of the description he gave, in 1868, that all movable weirs should fulfil the following requirements:[1] 1. To be worked by the natural force of the stream, without exposing the weir-keeper to danger. 2. To be under control. 3. To readjust automatically the little alterations in level of the upper water. 4. To be capable of resisting a violent shock. 5. To require for its erection merely such works as are ordinarily carried out on rivers. 6. To be fairly watertight. 7. To be applicable to greater heights than those of existing weirs. He appears to claim for his system that it fulfils the above conditions, and that it would be possible to apply it to a weir 23 feet high.

His description refers to a weir 10 feet in height (Plate 3, Figs. 5 and 6). The gate, or shutter, is hinged to a wrought-iron pontoon, which rises or sinks in a cast-iron frame, forming a conduit, and is hinged to the top of the lower side of it, so that both pontoon and shutter revolve on horizontal axes. The shutter is 9 feet 10 inches wide; its length is 16 feet 4 inches; but, being inclined when closed at an angle of 30° to the vertical, its vertical height is only 14 feet 2½ inches. The lower end of the shutter abuts against a sill, and its axis of rotation is placed 1 foot 4 inches above the centre of pressure. Near the top of the shutter there are three small valves, 3 feet 1½ inch high, and 2 feet ½ inch wide, turning on horizontal axes, and designed to be self-acting, so as to regulate the upper-water level when the weir is closed. The cast-iron frames, or conduits, can be put into communication with a reservoir (filled with water to the level of the upper pool when the water is high), or with the lower pool by means of sluice gates at their ends. When the weir is open the pontoon lies flat in the conduit, with the shutter resting upon it, the communication with the upper pool being closed, and open to the lower pool (Plate 3, Fig. 6). To close the weir, the lower sluice-gates are shut and the upper

[1] *Vide* "Cours de Navigation Intérieure," de Lagrené, vol. iii., p. 332.

ones opened; the pontoon rises in the conduit, revolving on the axis at the lower end, and raises the shutter, the power of flotation of the pontoon being sufficient to overcome the resistance and friction of the water and the friction of the apparatus (Plate 3, Fig. 5). To open the weir, the upper sluice-gates are closed and the lower ones opened, and the pontoon sinks into the conduit, dragging down the shutter upon it. A weir of this type was commenced at Port-Villez, on the Seine, but experiments, conducted on a large scale on the site of a proposed lock at Bougival, showing that the pressure of water needed for raising the pontoon was greater than could be obtained from the upper pool, without lowering to too great an extent the water below, and that therefore additional water-pressure would have to be provided for the efficient working of the weir, it was decided to abandon this system of weir at Port-Villez.

A movable weir of a totally different type to those previously described may be seen at the weir of La Monnaie, across a portion of the Seine at Paris. It was considered that an ordinary movable frame weir would be objectionable in the centre of Paris on account of its liability, when raised, to retain rubbish floating down the stream; and that a weir at that place should be kept out of sight as much as possible. M. Poirée accordingly designed, in 1853, a weir having three openings of 28 feet 9 inches, separated from each other by masonry piers. These openings are closed by wrought-iron cellular cylindrical segments. These segmental gates are connected at each end, by six radiating iron bars, to pivots fixed in the piers which form the axes round which they revolve. To close the openings, the gates are raised through a small arc by chains worked from the piers, which operation is rendered easy by the gates being counterbalanced by weights in the piers. This weir having been designed for a special purpose, it will probably remain a solitary example of its kind. A drawing of it is given in M. Malézieux's "Cours de Navigation."[1]

Full details of the different parts of the various kinds of movable weirs could not be given within the limits of one Paper; but they may readily be obtained by reference to the numerous articles on the subject which have appeared in the "Annales des Ponts et Chaussées" from 1839 to the present time, and also in the "Cours de Navigation Intérieure" of M. de Lagrené and of M. Malézieux, from which publications the Author has derived much information in preparing this Paper.

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[1] *Vide* "Cours de Navigation Intérieure." M. Malézieux. Atlas, plate 41.

It is difficult to arrive at a fair comparison of the cost of the different systems of movable weirs: the height of the weir, the nature of the foundations, and other circumstances, influence the cost of construction; and the cost of maintenance is also variable. Mr. Forsyth in his Report gives the cost per lineal foot of twelve movable shutter weirs on the Seine, varying between £44 and £71, with an actual average of £53. Mr. Manning gives an estimate of the cost of a certain length of each kind of movable weir, which, taken per lineal foot, is as follows: Needle weir, £40; shutter weir, £56; drum weir, £50; pontoon weir, £80. According to M. de Lagrené, the average cost of the twelve weirs on the Seine referred to above is as follows:

	£.	s.
Navigable pass, 10 feet high, per lineal foot	37	8
Overfall weir with foot-bridge	20	16

The average cost of three movable weirs on the Marne per lineal foot is as follows:

	£.	s.
Shutter weir across navigable pass, 9 feet 6 inches high .	51	4
Drum weir, 3 feet 3½ inches high	30	0

In reviewing the various systems of movable weirs, it appears that the bear trap is applicable merely to small heights; and though the opening and closing of the gates is performed by the water itself, the angle of inclination of the upper gate and the employment of a second gate render the system expensive, and it will not bear comparison with the simpler systems which have succeeded it. The drum weir, though possessing the great advantage of being easily moved and regulated by the water introduced through the sluices, has hitherto only been employed at overfalls, for which it appears to be very suitable. Owing to the depth below the actual sill required for the lower paddle and for the foundations of the drum, the expense such foundations would entail, if placed in deep water, and the cost of repairs, will probably preclude the employment of this system for weirs placed across the bed of the main stream. The pontoon weir, though possibly applicable for considerable heights, has hitherto hardly been sufficiently tried to admit of its being fairly compared with the older systems; and its large cost will probably hinder its general adoption, though in principle it satisfies many of the requirements needed for movable weirs. The two systems that have been most extensively introduced, those of M. Poirée and M. Chanoine, appear, as far as present experience goes, to be the

best types of movable weirs hitherto designed. The simplicity of the Poirée system, the small number of its parts, and the small size of each element of the dam, and its cheapness, render it specially applicable where the head of water to be retained is small. Probably, also, the modifications proposed by M. Boulé and M. Caméré will extend its adaptability to considerable heights.[1] Where, moreover, the navigation is continuous, and the flow of the river regular, and where it is not necessary to work the weir at night, needle weirs answer perfectly. But where the head of water to be kept up is large, the flow of the river torrential, and the navigation performed by flushing, the Chanoine system is the best. The needle weirs appear best adapted for heads up to about 8 feet, and sometimes, as at the Martot weir, where a needle weir is erected for the navigable pass, a shutter weir with a foot-bridge above is advantageously placed across the overfall, as the discharge of water can be better controlled by this method, and there is no danger of the weir being submerged when closed. On the Marne, shutter weirs are generally placed across the navigable pass, and the overfalls closed by a drum weir; whereas on the Upper Seine the discharge over the overfall is generally regulated by a self-acting shutter weir.

Rivers in England have been much neglected since the establishment of railways, and the consequent decrease in river traffic. Locks and weirs have been allowed to get out of repair, and weeds and mud have accumulated in the beds of the streams. Where weirs have been removed, to save the expense of maintenance, no attempt has been made to take down the side walls or aprons. Theoretically it might be desirable to restore the rivers to their natural condition, and give the river bed a fall corresponding to the fall of the land; but generally there is some navigation to maintain, or mills exist with vested rights, and the banks and adjacent lands have been somewhat accommodated to the existing water levels.

The neglect and silting up of rivers and the extension of subsoil drainage are the causes of the floods which so frequently occur in river valleys. The existing sectional areas of the rivers being inadequate in most cases to carry off the flood waters, even in the summer months, require enlarging. This can be accomplished in two ways—either by raising embankments at the sides, or by

[1] The level to which the water is to be retained above Port-Villez weir is 13 feet 1½ inches above the sill; and at a weir, just commenced on the Seine at Poses below Vernon, designed by M. Caméré, the hinged shutters will be 16 feet 5 inches high.

lowering and widening the bed. The former method would perhaps be the cheapest in the first instance, and an enlarged section be thus provided for the flow in time of flood, without any alteration being produced in the ordinary summer water level. When, however, it is considered that banks once formed have to be maintained, and in ordinary cases periodically raised, that the banks of all tributaries and water courses have to be similarly raised near the main stream; bearing in mind also the disastrous consequences that have resulted from such a course, of which the destruction of Szegedin is an instance, and the gradual raising of the bed of the river which inevitably follows, as in the case of the Po and the Japanese rivers, the Author is convinced that, unless absolutely necessary, and where, as in the fen districts, no fall is obtainable, the embanking of rivers beyond the tidal portion of their course is most unadvisable. The lowering of the bed and the widening at the sides afford the best and safest method of increasing the water-way, and of obtaining additional fall between locks. This course necessitates the alteration of all existing weirs, and the establishment in places of additional weirs to maintain the summer water level in dry seasons in the interests of navigation and of the riverside proprietors. The alteration of existing weirs would be indispensable in any scheme for mitigating floods, as the present weirs greatly impede the flow. Under these circumstances it appears to the Author desirable to investigate the types of movable weirs, so largely introduced in France and in Belgium, in order to ascertain whether they might not be employed with advantage on English rivers. Movable weirs, when lowered, present no obstruction to the stream; they can be carried to greater depths than the ordinary type of fixed weirs, and they can to a certain extent be made self-acting. Mr. Forsyth and Mr. Manning, in their reports above alluded to, express opinions unfavourable to the adoption of movable weirs on the river Shannon; but the Author is of opinion that a subject which has occupied the attention and exercised the ingenuity of engineers in France for forty years, and has successfully borne the test of long practical experience, is well deserving the careful consideration of English engineers.

The Paper is accompanied by a series of diagrams, as well as by small scale drawings, from which Plates 1, 2 3, and 4 have been engraved.

(*Paper No. 1670.*)

"Movable Dams in Indian Weirs."[1]

By Robert Burton Buckley, Assoc. M. Inst. C.E.

The weirs which now exist across Indian rivers have been mostly constructed for the purpose of raising the level of the water during the dry season, in order to force it into canals taken off, sometimes on one side, but often on both sides, of the rivers from above the weirs. In some instances the weirs are temporary erections, which are made every year after the season of floods; but in most cases, especially in the more modern works, they are permanent masonry structures. The following Table gives the dimensions of some of the more noted permanent weirs:

Name of River.	Length of Weir.	Height of Crest of Weir above Summer level of River.	Rise of the River in Floods.	Dimensions of Movable Dam (or Undersluices) of the Weir.
		Feet.	Feet.	
Godavery .	Four lengths aggregating $2\frac{1}{4}$ miles .	12	28	
Kistna .	1,300 yards .	16	36	Fifteen vents at each end of the weir, each 6 feet wide.
Mahanuddee	$1\frac{1}{4}$ mile . .	12	21	Ten vents of 50 feet each at the middle of the weir.
Cossye .	1,700 feet .	9	18	Nine vents of 50 feet each at one end of the weir.
Sone . .	$2\frac{1}{2}$ miles in a continuous length . .	8	18	Three separate movable dams, one at each end and one at the centre of the weir; each consists of twenty-two vents, 20 feet 7 inches long.
Lower Ganges	5,000 feet .	8	13	Forty-two vents of 7 feet each at one extremity of the weir.

[1] The discussion upon this and upon the preceding Paper was taken together.

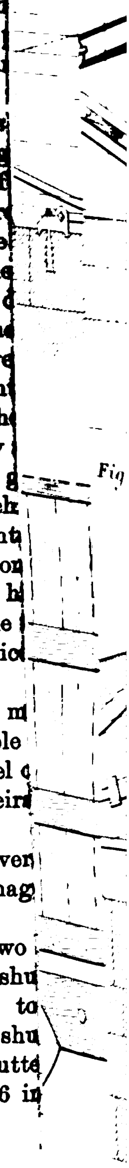
The first effect of the construction of a weir across a that the pool formed by it gradually silts up, partly by during floods, of matters in suspension in the water, and by the gradual forward motion of the bed of the river whic in all streams, but is only visible to the eye in rivers wit beds. Islands begin to form, which would in time o navigation across the river above the weir, and would the water, in the dry season, from finding access to the ca off from the pool.

In order to obviate these difficulties, every weir has furnished at one extremity, or at both extremities, accordin canal or two canals are taken off from above it, with a set o or movable dams. In very long weirs, such as that acr Sone river in Bengal, another movable dam is placed in the to assist in keeping open a navigable channel across the That these movable dams may thoroughly perform their is necessary that they should be large and powerful. In th first constructed—in the Godavery, the Kistna, the Cauv other weirs—it was the custom to make sluices with ven 6 feet wide, and raised to only about half the height of th In these works the scouring sluices were closed in the dry either by balks of timber dropped one after another into the g in the pier, or by gates, sliding in vertical grooves, which were raised and lowered from above by levers working int rods attached to the gates. This system necessitated the con tion of a masonry superstructure to above the level of the h flood, which opposed great resistance to the free flow of the and stopped floating *débris* in the river, so that the sluic unfrequently became choked with trees and brushwood.

As these earlier works were inefficient, in the more m works much larger openings have been left, and movable have been erected, with no superstructure above the level o weir, so that floods pass without obstruction over the weir depth, it may be, of 18 or 20 feet.

The system adopted on the Mahanuddee and Cossye river modification of that introduced by MM. Thénard and Mesnag the river Isle, in France.

The movable dam (Plate 5, Figs. 1, 2, 3), consists of two of wooden shutters, placed back to back; both rows of shu are hinged by massive hinges to a beam bolted down to flooring of the weir; the back, or down-stream row of shu is about 18 inches higher than the front row. The shutte the Mahanuddee weir are about 7 feet wide, and 7 feet 6 in



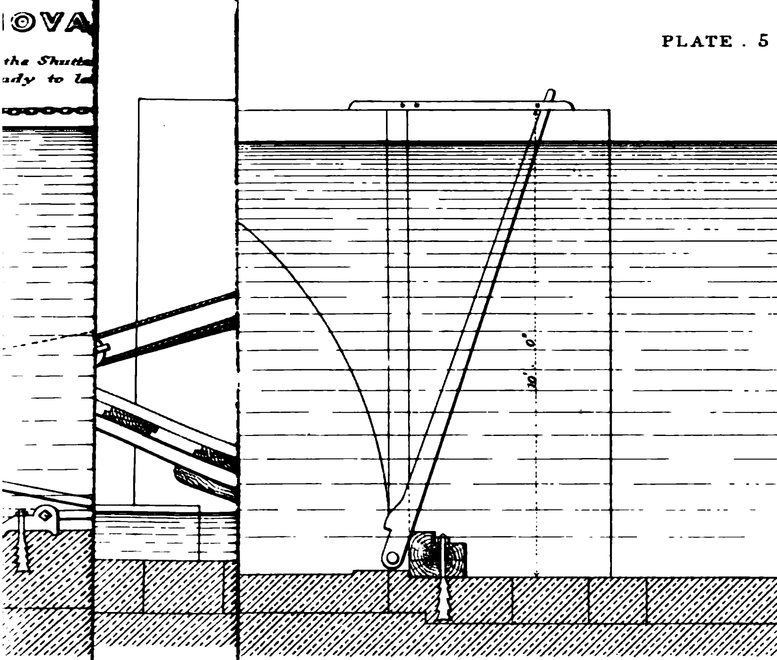


Fig : 9.

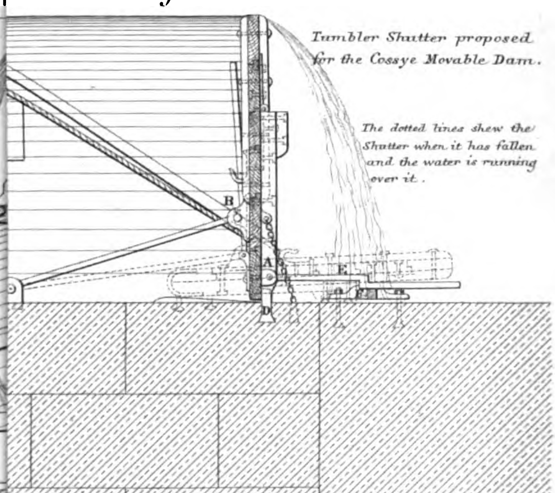


Fig : 7.

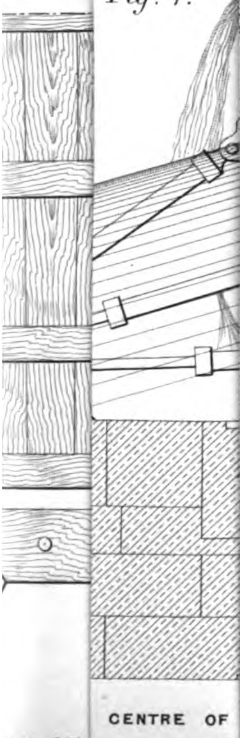
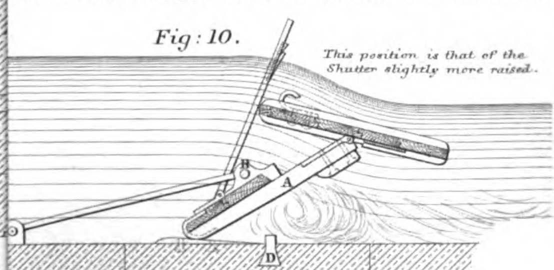


Fig : 10.



and 9 feet high respectively. There are seven shutters in each bay of the movable dam or undersluices, and ten bays or vents, each 50 feet wide; each bay is separated from the next one by a stone pier 5 feet thick, in which the gearing for working the shutters is fixed. In the Cossye weir there are only three bays of 50 feet; each bay contains eight upper and eight lower shutters, the upper being 6 feet, and the lower 7 feet 9 inches high. The front shutters fold down on the floor up stream; the back shutters down stream. A beam in front of the upper shutter is bolted down to the floor in such a position that the top of the shutter is just in a line with the up-stream face of the beam; the top of this beam is about 3 inches below the top of the central beam, so that the shutter slopes slightly downwards from its heel when lying on the floor. The ends of the retaining chains are fastened to the beam in front, and the other end to the castings on the back of the battens of the front shutter. These chains, on each shutter, are not fixed in a plane at right angles to the face of the vertical shutters, but diagonally, both sloping inward towards the centre of the shutter; the object of this is to prevent the upper half of the chains falling on the top of the lower half under the shutters, and preventing them from going down flat on the beam G. The chains now fall of their own accord, as the shutters descend, into a loop; a slight hollow is purposely left in the floor in which this loop lies, so that when the shutters are down they are clear of the chains. The front shutters being down, hooks, attached to the bar in front of each shutter, are revolved by the bar until they catch the castings bolted to the face of the shutter. When the Mahanuddee shutters were first put up, it was thought that they would lift of their own accord if these hooks were thrown out of gear when the stream was flowing through the sluices; but this only happened occasionally, when some bank or impediment directed the force of the stream under the shutters; and it was found that, even if the shutters were lifted an inch or so, the stream sometimes pressed them down again on the floor instead of lifting them. Another difficulty was also met with. After the shutters had been down perhaps for a few months, small water-worms used to construct cells between the shutters, the beam, and the floor—cells which stuck the shutters down so tightly that force was necessary to break the crust. For these reasons the following plan has been adopted. A rod of iron, about 2 inches in diameter, is fitted along the face of the beam in front of the upper shutter; at one end of this rod a handle is arranged, so that the rod can be revolved about one

quarter of a revolution. The rod bears in the castings fixed to the face of the beam. On this, under the centre of each shutter, a cam is keyed, which, as the bar revolves slightly, lifts the shutter as soon as the hook is out of gear. The seven cams fixed to each rod to lift the seven shutters in each bay are set at slightly different angles, so that, as the rod revolves, they come into operation on the shutters one after another. The back shutters, which are always used to retain the pressure of the water when the movable dam is closed, are, when erected, inclined at an angle of about 15° down stream. They are supported at the back by spur struts, one of which is hinged to the batten at the back of each shutter at about $\frac{3}{8}$ of the height of the shutters from the top; to the first shutter in each bay two struts are fitted. Two other struts are hinged at a similar height to a T-iron, which is hinged to the castings fixed on the centre beam. These last struts and T-irons are altogether independent of the shutters; they are loose from them, and are put up separately after the shutters are raised. The heels of all the struts rest, when the shutters are up, in the lugs of the iron shoes which are bolted down to the floor. The shutters are raised one by one by men standing on the floor below. They first lift the shutters—there being, of course, little or no water on the floor—and support them by the first-mentioned struts. After any two contiguous shutters are up, the strut between them is raised, the foot of the T-iron is inserted between the shutters, and they both bear against the head; a joint fairly water-tight is thus formed. To let the back shutters fall when a flood is expected, a bar, arranged to slide in guides on the floor close to the heels of the struts, acts in the same manner as the bar used in M. Chanoine's falling dams in France. Studs are welded on to it at intervals, which catch the heels of the struts as the bar is drawn along the floor by the gearing fixed in the pier. These studs are so fixed that the shutters fall one after another, the studs coming into gear with each pair of struts consecutively, the shutter which has the two struts L attached to it being the last to be let down. As the first shutter falls, the second is supported by its own strut, and the neighbouring T-iron strut, at the joint between itself and its neighbour. When the sixth shutter is let down, the seventh, were there not two struts attached to it, would be twisted by the force of the stream; it is to prevent this that double struts are attached to the last shutter.

As there is generally little or no water on the apron of a weir across an Indian river when the sluices are opened, men can

nearly always walk about behind the shutters as they are being let down: indeed the back shutters are not unfrequently let down by men with crowbars pushing the struts out of the lugs on the shoes; or sometimes the men knock the struts out of the lugs by a wooden beam which they jump against the struts.

This form of movable dam has one great disadvantage in the severe shock which the retaining chains have to bear. These used to be constantly breaking both in the Mahanuddee and Cossye weirs. On the Mahanuddee there are now 1¼ inch stud chains; they were at first ⅞ inch on the Cossye weir. The constant breaking of the chains gave so much trouble that the engineer in charge has substituted folding links (Fig. 2). On one occasion the front beam was pulled up from the floor. The strain on each chain of the shutters of the Cossye weir, 6 feet high by 6½ feet broad, is about 16 tons. This kind of shutter has never been raised against a greater head of water than about 6 feet 9 inches. The front shutter is only used when the level of the river has fallen to at least 6 feet above the floor of the weir, and frequently the engineers hesitate to use the shutters until it has fallen lower. The mode of working this form of dam is simple. Supposing the shutters to be flat on the floor, and the stream running through the sluices, if it is desired to lift the front shutters, the bar in front of the upper beam is made to revolve by the handle on the pier, the hooks are released, and the cams on the bar raise the shutters, one by one, a few inches above the beam; the stream then rushes beneath and throws the shutter violently up into place. When all the front shutters are up the men go below on the floor of the sluice and lift the back shutters by hand, having first drawn back the disengaging bar. The struts are placed in the lugs, and the back shutters are then ready to receive the pressure of the water.

It has been found that in a dam constructed on this principle, 500 lineal feet of shutters can easily be lowered in one hour with a head of 6 feet of water, and that with a similar head an equal length can be closed in twenty-five minutes; that three men standing on the floor are sufficient to knock away the back struts, with safety to themselves; that the back shutters are not damaged as they fall on the floor because water escapes as each shutter falls sufficient to form a cushion for the other shutters to fall into. Twelve men are necessary to lift each of the back shutters into position.

In the Sone weir (Plate 5, Figs. 4, 5, 6, and 6*a*) each of the three sets of river sluices is fitted with a movable dam, designed by Mr. Fouracres; each set is divided into twenty-two openings,

each opening is 20 feet 7 inches wide; the piers between the openings are 4 feet thick and 32 feet in length, and the tops of the piers are 10 feet above the bed of the river, that is 2 feet above the crest of the weir wall, which is 8 feet above the sluice floor. About the centre of each opening the level of the floor is raised 9 inches, and thicker floor stones are laid; the object being partly to have heavier stones for the lower edge of the shutter to oscillate against, and partly to form a recess, so that the shutter may lie snugly on the floor. Each opening is fitted with two shutters; the up-stream one is 21 feet 3 inches in length, and 9 feet 9 inches high. This shutter is pivoted at its lower edge, and turns on two strong cast-iron gudgeons working in sockets built into the piers. The shutter being 8 inches broader than the width between the piers, has, when vertical, a bearing of 4 inches on either side against each pier; but this has been found unnecessary, as the telescopic struts are sufficiently rigid to withstand the pressure; and when the packing in the hydraulic brakes becomes worn, the shock against the pier injures the masonry. The piers are recessed 5 inches deep for the extent required to enable the shutter to oscillate freely between the horizontal and vertical positions. At the back of the shutter are fitted six struts, which are the chief novelty in this system, and answer the double purpose of supporting the shutter when vertical, and of breaking the force of concussion against the piers when the shutter is suddenly raised with a 9-feet depth of water running through the sluices. There are six backstays to each shutter; each consists of two cast-iron brackets, the first firmly attached to the stone floor, the other to the shutter; to the lower bracket is hinged an iron bar, $2\frac{3}{4}$ inches in diameter, and to the upper bracket a wrought-iron pipe, $3\frac{1}{2}$ inches internal diameter; the bar is inserted into the pipe, and the two thus form a telescopic strut. On the lower extremity of the bar is a collar which, when the shutter is vertical, is in contact with a ring shrunk on the end of the pipe; the pipe thus forms a rigid strut supporting the shutter at the back. On the rod, which is $\frac{3}{4}$ inch less in diameter than the pipe, are shrunk two guide rings, and above the upper ring is fixed leather packing similar to that of an hydraulic ram; this packing makes the head of the rod into a piston, which, when exposed to the force of the water, fits tightly into the tube. In the pipe are three small holes $\frac{3}{16}$ inch in diameter; the lower one is about 4 inches above the leather packing of the rod, when the shutter is horizontal and the telescopic joint drawn out; another hole is at the top of the pipe, a little above the leather packing

when the shutter is vertical and the telescopic joint shut up; between these holes is the third one. The action of these backstays is as follows: When the shutter is down and the telescopic joint drawn out, the water running through the sluices enters and fills the pipe through the $\frac{3}{16}$-inch holes, and flows probably past the piston, for the leather packing becomes loose as the rod is drawn out; the pipe is then full of water. As soon as the shutter begins to rise, and the telescopic joints consequently begin to shut, the leather packings, being opposed by the water in the pipes, become tight, and the water in the pipes can only escape through the small $\frac{3}{16}$-inch holes; its efflux is therefore much retarded, and a brake is placed on the motion of the shutter, the resistance increases as the piston passes the first hole, and attains a maximum after the piston has slid past the second hole, and the shutter comes up gradually to the vertical position, the water being expelled in a jet from the topmost hole. When the shutter is lying down on the floor, and the telescopic backstays are extended at full length, the holes in the pipes rest on indiarubber buffers secured to the back of the shutters. This completely closes the holes and prevents sand or silt accumulating within the pipes. At first the holes were placed on the top of the pipes, and the pipes became clogged by sand.

The backstays have now been at work for five years; the leather packing lasted four years before it had to be renewed.

A vertical bar, with a catch at the lower end, worked by a handle on the pier, is fixed to retain the shutter horizontally until it is required to be lifted.

The down-stream shutter is 20 feet 7 inches long and 9 feet 7 inches high, fitting between the two piers without any recess; on the front of this shutter seven tension bars are hinged in cast-iron brackets. The shutter oscillates about the centre of the bracket pin, and the tension rod about the centre of the pin of the bracket which is fixed to the floor; so that, when the shutter falls down stream, the lower part slides along the floor towards the fixed bracket, and finally sinks into the horizontal position shown by dotted lines. At the back of every third shutter a trough is formed by a curb of ashlar 12 inches high, which stretches across from nose to nose of the piers; this trough remains always full of water, and forms a cushion to break the fall of the shutter should it be necessary to let it down when there is no water on the apron. After every third shutter has fallen there is sufficient water on the apron to form a cushion for the other shutters to fall into.

The tension rod is hinged to the shutter a few inches below the

centre of pressure when the water is level with the top of the shutter, so that when the river rises slightly, the centre of pressure is soon raised sufficiently above the centre of oscillation of the tension rod to overcome the friction of the lower edge of the shutter on the floor; the shutter then falls into the horizontal position, and the flood is free to pass. A chain at each end retains the shutter, if necessary, against any head of water. Pieces of kentledge are fastened to the front of the shutter to keep it steady and to prevent it from being raised by the water. The shutter when lying on the floor is inclined slightly upwards, the top being a few inches higher than the heel; the stream flowing over it impinges on the inclined surface of the shutter, and thus presses it down tightly on the floor with a pressure varying with the velocity of the stream. The shutter remains steady so long as the water is flowing with a velocity of more than 2 feet a second. The usual velocity is about 17 feet a second. The kentledge is only wanted in case the water below the weir rises nearly level with that above, when the velocity would be so small that the shutter might float and knock about in the stream. In each of the upper shutters is a small sluice, which can be opened by hand. In front of the up-stream shutter a groove is cut from top to bottom of the piers, into which logs of timber can be dropped when repairs are necessary, or in case any accident should prevent the shutters from being lifted.

During the dry season the water is retained in the weir-pool by the back shutter, which is secured in position by the two chains; one end of each of these chains is fixed to a stud in the centre of the pier, the other end is slipped into a let-go gear on the top edge of the shutter. When floods are expected, and it becomes necessary to make arrangements for opening the movable dam, the back shutter gear is let go, so that, should the floods rise suddenly, the shutters will upset of their own accord and let the water pass freely.

At any time when it is desired to close the movable dam, a light portable foot-bridge is run across on the top of the piers, which are then probably a few inches above the water-level above the weir, so that men can easily pass along the whole length of the dam. In the next place a hook, having at its upper end a cranked shoulder fitting into a lever attached to the pier, is placed under the angle-iron which is fixed on the top edge of the front shutter; the lever is then drawn tight by a light three-fold tackle attached to the pier; when this has been done on both sides of the shutter and all is ready, the catches, which keep the shutter down, are withdrawn, the men draw down the lever with the tackle until the upper edge of the shutter has been lifted about 8 inches, and the

stream then raises the shutter slowly into the vertical position, the hydraulic brakes preventing any shock.

It has been found in practice on the Sone weir, that these shutters can be safely lifted, without shock, against a head of 10 feet of water, that is when the water in the pond above the weir is level with the top of the piers; they have been frequently worked under these conditions; the greatest head against which other shutters on any other weir have been lifted is believed to be about 6 feet 9 inches only. It is a sight worth seeing to watch a stream of water 20 feet broad and 8 or 9 feet deep, flowing with a velocity of 17 to 20 feet a second through the sluices—with a difference of 10 feet between the water-level above and below the sluices, to be suddenly closed by a single gate 20 feet long by 10 feet deep. The water, when the shutter reaches the vertical, rises in a wave 1 foot or 2 feet above the top of the shutters and piers, and flows over for a few seconds before it sinks to the mean level of the stream.

When the front shutters have been raised, it is advisable to put up the back shutters at once, and to refold the front shutters on the floor; because, should a flood come down unexpectedly, the back shutters will be ready for any contingencies, and since there is always danger of silt, sand, stones, and rubbish collecting before the front shutters.

To raise a back shutter the tackle used for hauling down the levers of the front shutter is again employed. One block being hooked to an eyebolt on the upper edge of the back shutter, and the other block to a rag-bolt in the side of the pier, four or five men haul on the tackle and pull the shutter into a vertical position. When both shutters are up, the men proceed to lower the front shutter. The valve in the front shutter is opened, and the space between the two shutters filled with water; the back shutter now retains the whole pressure, and the front shutter simply rests in the water, the pressure on each side of it being equal. The front shutter is then pushed up stream by two men on each pier pressing it down with a pole or boat-hook on the floor, so that the catches L can be brought into gear, and it is safely fixed ready to be again lifted. Should it be found necessary to upset the back shutter when the water above the weir is below the top of it, and when the centre of pressure is consequently below the axis, a boom or spar, with an eye-bolt at one end, is applied against the top of the shutter on the batten next the pier, and the tackle before used is hooked into the eye-bolt at the other end of the spar, which is then boomed out against the shutter until it falls. It takes about

half an hour to entirely manipulate each bay of the dam; but, if necessary, the whole of the front shutters, 500 feet long, could be raised in about four hours by eight men; the back shutters could be raised afterwards.

When this system of movable dam was first erected on the Sone weir, the beams, which are now fitted in the front of each upper shutter, and which form a recess on the floor for the shutter to rest in, were omitted; but they were found necessary, as during one season three or four shutters were torn up by the pressure of the stream beneath. Now they remain without any fear of damage.

The advantages of this system of movable dam in rivers subject to high floods, and when it is not required to open the dam until the river has risen to a certain defined level, as compared with the systems of MM. Thénard and Mesnager, Poirée, Chanoine, Desfontaines, and Girard, are:—(1.) That the entire dam can be speedily opened where the river has risen above the top of the back shutter. This advantage is obtained by all the above systems except that of M. Poirée. (2.) That the dam can be opened gradually and automatically with the increasing rise of the river. M. Chanoine's system is the only one of the French systems which will admit this, and that not entirely. (3.) That the dam can be closed against a much greater head of water than any other dam which has not some working parts below the level of the floor or crest of the weir on which it has been fixed. (4.) That all the working parts can, when the front shutter is up, be easily got at for repairs. (5.) That there is no shock on the masonry or working parts, as in the system of MM. Thénard and Mesnager; and that there are no working parts below the level of the floor, as in Desfontaines' system, liable to be filled with sand, silt, and pebbles.

Mr. Fouracres' three or four years' experience in working the movable dams of the Sone weir has suggested the following modification of this system (Plate 5, Fig. 7). Instead of recessing the shutters into the floor for the purpose of forming a quoin along the back of the shutter against which it presses when vertical, he would do away with the gudgeons on which the shutters now revolve in the piers, and would hinge the shutters about every 4 feet, on wrought-iron hinges firmly fixed by rag-bolts to the floor, rounding the base of the shutters so that they would staunch themselves on the floor when they were vertical. The hinge of the shutters would be so made that when they were folded down there would be a space of about 3 inches between the heel of the shutters and the stone floor; and the floor of the sluices below the folded shutters would be recessed about 1 inch, so that any small stones or sand which might accumulate when the shutters were upright

would not interfere with their closing when they were folded down. Instead of having the shutters in lengths of 21 feet 3 inches, with piers between each set, the shutters would be made in lengths of about 7 or 8 feet, with intervals of 50 feet between the piers. Moreover, in place of the beam in front of the shutters, Mr. Fouracres would substitute other arrangements; as the shutters would be slightly inclined downwards against the stream, they would have no tendency to rise from the pressure of the current beneath. The bar A would be made to revolve by a handle at each pier, and cams attached to it would first release the hooks from below the lugs on the castings, and when the hooks were clear, the other cams would raise the shutters slightly, until the stream rushing beneath pressed them up to the vertical position. The stream, which would flow with great force beneath the shutters for the first few seconds after the cams had raised them, would sweep through the 3-inch apertures below the heel of the shutters any deposit that might have accumulated beneath them while lying prone. The back shutters would be made the same width as the front ones. They would then be so light that six or eight men could easily lift them into place, or they might be run up with tackle attached to an eye-bolt in the upper shutters.

The movable dams, or undersluice shutters, of the Sone weir, have, after an experience of five or six years, been found insufficient to keep open a navigable channel across the weir. The pool above the weir has silted up so much, that when the water is level with the crest of the weir, that is when the water is 8 feet above what used to be the bed of the river, it is with difficulty that a boat drawing 3 feet of water can be got across from the canal on one side to that on the other. Many islands have been formed 1 foot or 2 feet above the level of the crest of the weir, and are yearly increasing. To facilitate navigation, and to raise the level of the pool with the object of obtaining a greater depth of water upon the head sluices of the canals, it has been decided to put a movable dam, 2 feet high, along the whole length ($2\frac{1}{3}$ miles) of the weir (Plate 5, Fig. 8). The design is similar to that of the back shutter of the Sone dam previously described. Each shutter is 18 feet long by 2 feet 3 inches high, of light plate-iron stiffened with angle-irons. The shutters are hinged to tie-rods 4 feet long, which are capable of oscillating at their up-stream end on a horizontal pin attached by a rag-bolt to the crest of the weir. The point at which the tie-rods are hinged to the shutters is about 3 inches below the centre of pressure of the water when level with the top of the shutters; the shutters are, therefore, on the point of overturning when the water is at that level, and will overturn

and fall into the recess provided for them when the water rises higher. They will remain in that position all the flood season, and will be raised after the floods by hand. Four men can raise these shutters, when a depth of 6 inches or 8 inches of water is flowing over the crest of the weir, almost as quickly as they can walk.

A movable dam similar to this was fitted to the Panchorah weir on the Cossye river, but it was afterwards found more convenient to substitute grooved standards and planks. Small movable dams across distributaries in the Midnapore district of Bengal have been constructed on this principle, but they have not been favourably reported upon by the resident engineer.

Another form of movable dam has been proposed by Mr. Fouracres, which, although it has not fulfilled successfully the essential condition for all dams on Indian weirs, namely, that they should be capable of being lifted without shock against a head of 8 or 10 feet of water, is nevertheless worthy of attention, for it possesses several advantages as regards lifting against a head of water over the system of M. Chanoine, to which it is in some respects similar.

The 6-feet shutters (Plate 5, Figs. 9 and 10) might be made in any convenient lengths. Each shutter consists of two parts. The lower part is made of two wooden battens, A, 4 feet long, attached at their lower ends by a longitudinal plank about 2 feet broad. The upper shutter is hinged to the top of the battens of the lower one in the centre of its height; it consists of planks and battens with a counterbalance weight and hook at its lower edge. The lower shutter is hinged by a casting B to a tie-rod 5 feet long, the up-stream end of which is hinged to another casting, firmly bolted to the cut-stone floor of the weir. This casting B is attached to the lower shutter at such a point that, when the shutter is in the position shown in Fig. 5, the centre of pressure of the water on the whole shutter is about 3 inches or 4 inches above the centre of the castings B. Short chains C are attached to the heel of the lower shutter, to prevent it riding over the stops D, which bear against the heel of the lower shutter when it is in the vertical position. To the heel of each lower shutter two wrought-iron bars E are hinged. The bars, when the shutter is erect, catch into castings bolted to the floor of the weir behind each shutter; and when they are in gear the shutter is retained erect against any head of water. A draw-bar F slides along the castings at the back of the shutters, by means of which the catch-bars E can be thrown out of gear.

If the shutter is in position, with the water level with its top,

the catch-bar E being in gear with the castings, it will remain in that position until the draw-bar F releases the catch-bar E, when it will fall flat on the floor, for, when erect, the upper shutter has no tendency to revolve about its horizontal axis, as that axis is always above the centre of pressure of the water on the upper shutter. If the floods rise above the level of the top of the shutters, a movable dam constructed on this principle may be opened immediately by releasing the catch-bars at the heels of the shutters; or, if it be desired that the dam should be self-acting, as regards opening, the catch bars may be thrown out of gear before the floods arrive, and the shutters will then fall of their own accord one after another in the order of their sensibility. To raise the shutters from the floor against a head of water is rather troublesome; the hook on the upper shutter has first to be caught by a boat-hook from a barge moored in the river above the weir. When this is done the shutter is gradually pulled up by a winch on the barge. As it is being raised the upper shutter is kept inclined slightly against the stream, so that it presents little more than the area of its cross section to the resistance of the water. The lower shutter, as it gradually rises into the vertical position, presents above its axis of rotation B only the area of the battens A to the resistance of the stream; but below that axis the boarding, which is attached to the heels of the battens, opposes a considerable area to the stream, so that, after the shutter has been slightly raised from the floor, the pressure on the planks below the axis B assists the lower shutter into the vertical position; when the lower shutter has reached this position it rests against the stops D, and the catch-bar E falls into gearing with the castings; the lower shutter is thus fixed securely. As soon as it is ascertained that this is the case, the upper shutter is temporarily fastened in a horizontal position by a batten which is hinged to the front of the lower shutter. This is done that the water may flow over the top of the planks on the heel of the lower shutter, and that the level of the water above the dam may be raised as little as possible. After all the shutters have been raised, the battens holding the upper shutters are pulled away by a boat-hook, and the upper shutters, by the action of the counterweight and by the force of the stream, rise into the vertical position. There can be little doubt that the best of the systems described in this Paper is that which is in use on the Sone weir. It might be improved, but for simplicity of construction and absence of machinery liable to derangement it is unique.

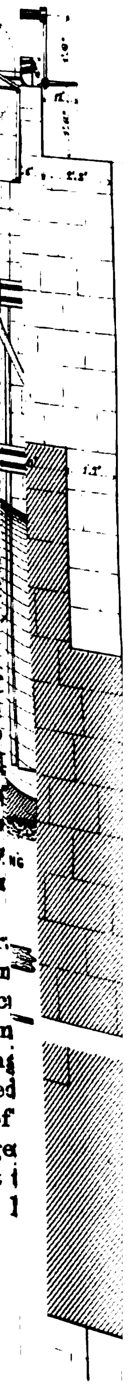
The Paper is accompanied by a series of drawings, from which Plate 5 has been engraved.

Discussion.

Mr. Vernon-Harcourt.

Mr. VERNON-HARCOURT said, that since he presented his the Institution he had visited France, with the express p inspecting some of the most recent of the different weirs in that country, and also to find out what modific improvements had been made, and in order to converse w French engineers who had had most experience in that p branch of river engineering. The first weir to which h call attention was the bear trap. The diagram (Plate 2 showed a section of the weir in France at Laneuville- That was one of the earliest movable weirs introduced, bei American type, called the bear trap. But it had been fo though the intention was, as he had explained in his Pa the gates should be raised by the pressure of the upper po through the sluice, that pressure was not generally suffici the water was lowered to too great an extent in the lowe allow of proper navigation. It had, therefore, in practice be necessary to raise the upper gate by ropes or chains; be order to get a sufficient water-pressure in the sluice it w necessary to have an accumulator on the banks, or a large r This weir, therefore, possessed rather an historical than a interest. No more weirs of that type had been made in Fra it might be regarded as rather a clumsy weir. The needle a very different type. It was first used by MM. Poirée and C The novelty of the weir was not the needle, which had b in French stanches before any of these movable weirs troduced. The stanches which they then used were very to those which might be seen at the present time in so of the Thames above Oxford, and which used to exist river Severn, a description of which had been given by Mr. in 1845.[1] Those on the Severn were closed by planks, an on the Thames generally by rimers and paddles. The pec of M. Poirée's system was the movable frame that could be down; but he preferred calling it the needle weir to distin from other systems in which similar frames were employe weir shown on Plate 2, Fig. 3, was not the largest type of weir that had been erected in France. It was the type ge used on the Meuse, and also on the Moselle. The largest weirs used in France were those at Suresnes, Bezons, and

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iv., p. 111.



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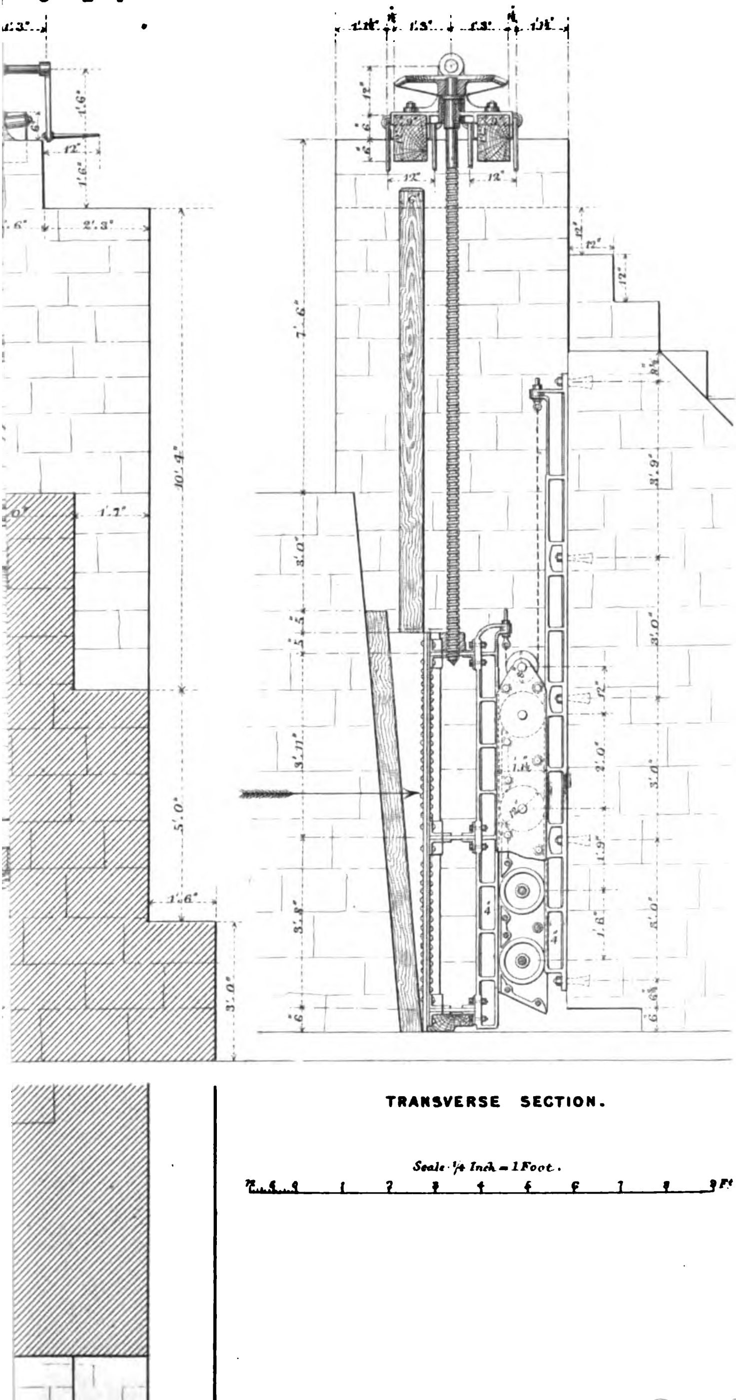
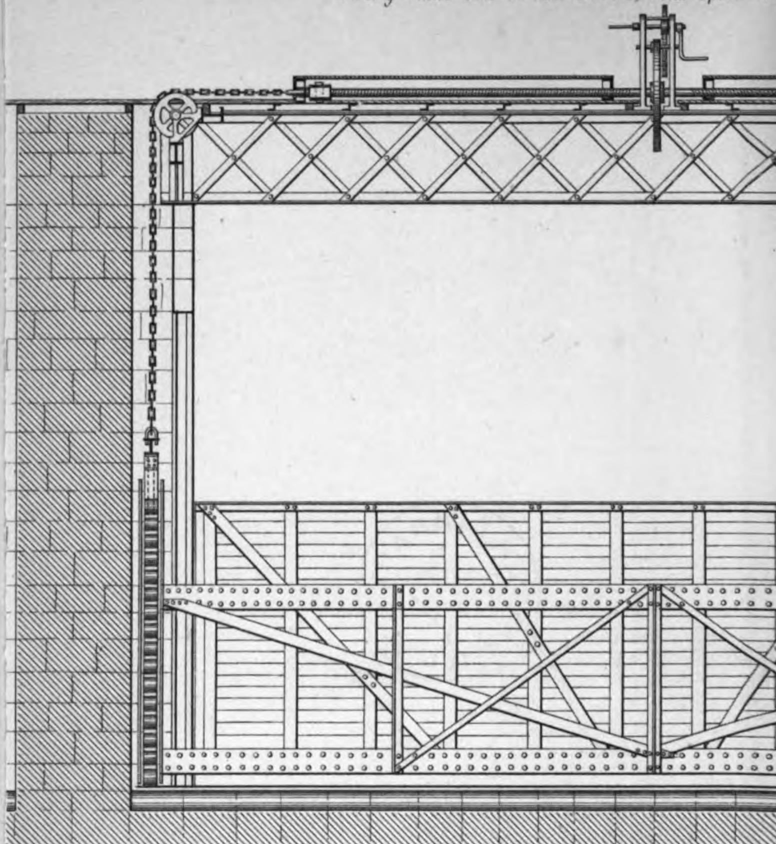


TRANSVERSE SECTION.

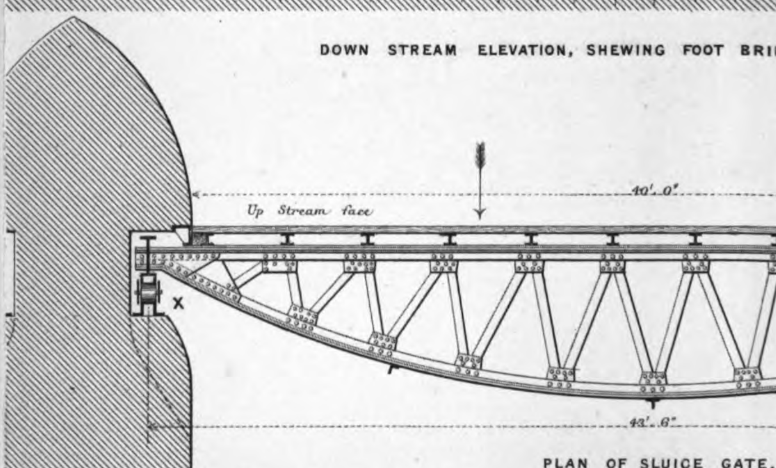
Scale 1/4 Inch = 1 Foot.

12 6 0 1 2 3 4 5 6 7 8 9 Ft

Lifting Sluice Gate on Free Rollers; Clear Span 40 f



DOWN STREAM ELEVATION, SHEWING FOOT BRID



PLAN OF SLUICE GATE.

Scale 1/8 Inch = 1 Foot.

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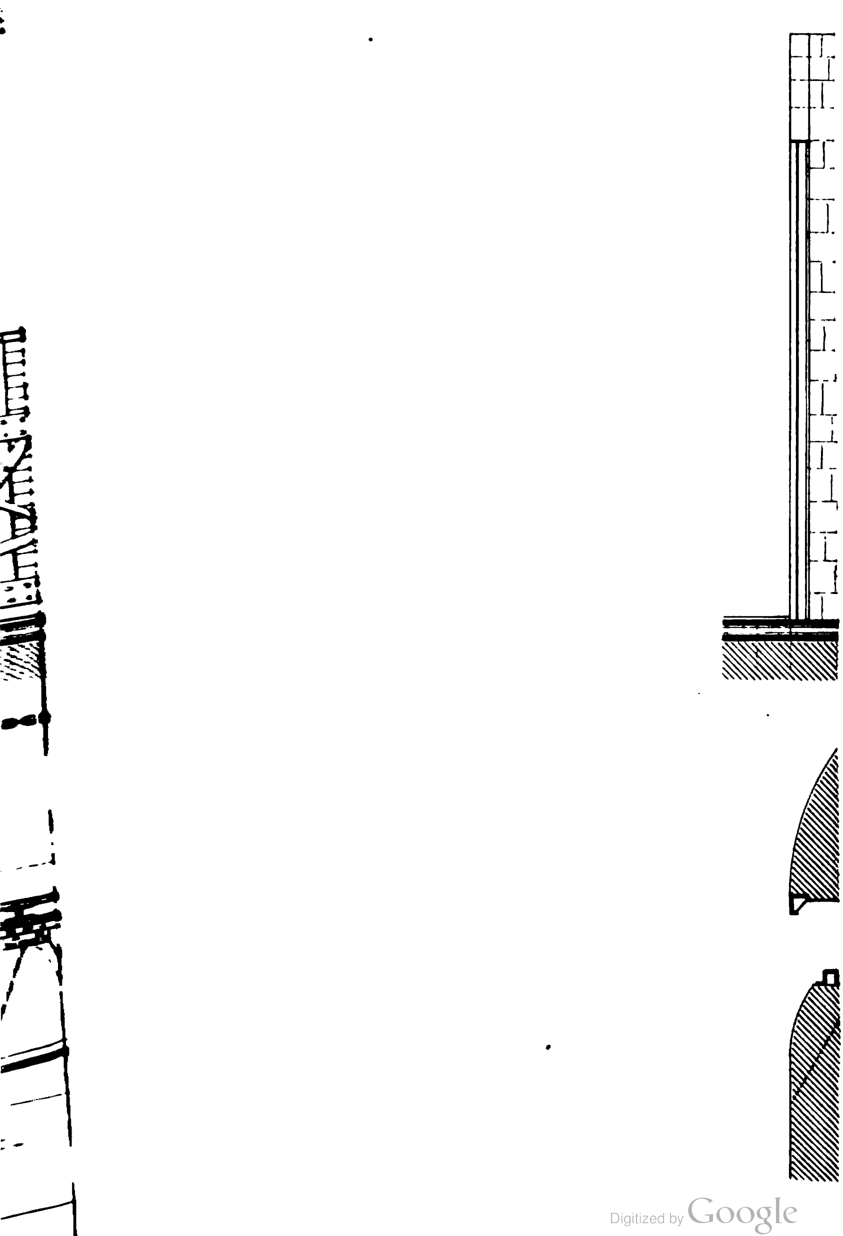
r. Vernon-
arcourt.



Mr. Vernon-Harcourt.

the latter being the weir that separated the tidal from the non-tidal portion of the Seine. He had visited the weir at Suresnes. This weir was higher than Teddington weir, being able to hold up 10 feet of water, whereas the height of the Teddington gate was only 6 feet. If the weights were compared, it would be found that at Teddington each frame weighed about 1 ton, whereas at Suresnes each frame only weighed about 4 cwt., showing that there was a great difference between the weight of the frames put up in France and those put up at Teddington. It ought, however, in justice to be said, that the frames at Teddington were about double the distance apart of those at Suresnes, and at Suresnes the foot-bridge was not raised to such a high level as at Teddington. It appeared to him that one objection to the Suresnes weir was that the foot-bridge that went on the top was about level with the water in the upper pool, and therefore it might be difficult, and in one instance was proved to be impossible, to remove the needles in time when a flood came suddenly down. He thought, however, there would be less difficulty now than there was in 1873, when the weir was regularly submerged, as M. Belgrand had now established such a good system of warnings that all the weir-keepers could be warned when a flood was coming down. In fact, on one occasion in 1876, M. Belgrand was able to predict the greatest flood height in Paris to within ½ inch three days before it occurred. A plan was adopted at Suresnes of regulating the discharge of the weirs without removing the needles at all, by just pushing forward the needle at the top, and then putting a small block of wood to keep it in place. When the water had to be raised it was only necessary to remove the block and the needle returned to its place. That obviated the difficulty of removing the needle. When he was at Suresnes, several of the needles were blocked up. There were no mechanical arrangements for removing the needles. He asked the weir-keeper about it, and was told that all he did was to push each needle away with his foot at the top, and the needle fell out of its place. There was a rope attached to it, and by that means it was brought up on to the bank. But on the Meuse, where there were needle-weirs of about the same size, there was a bar, near the top of each frame, supporting the needles that turned on a vertical pivot. There was also an arrangement for releasing it from its point of support on the adjoining frame, when the bar would turn round its pivot and release the needles. The Suresnes weir was built in 1866, and was the most recent needle weir on the lower Seine. It maintained the level of water through Paris up to Port-à-l'Anglais

r. Vernon-arcourt.

weir, a little above the confluence of the Seine and the Marne. No doubt some of the members had noticed the weir at La Monnaie, which was in the centre of Paris. That had been erected some years previously to the weir at Suresnes, and was practically not used now, except sometimes in the winter in order to prevent an undue rush of water during flood passing under some old bridges in Paris. The weir could be raised 3 feet 3 inches. It was generally under water, and was under water when he saw it. The movable shutter weir as adopted at Port-à-l'Anglais, was shown on Plate 3, Fig. 1. It was the largest of the shutter weirs in France. There was another shutter weir, without the foot-bridge, at the same place, and when he went to see it, it was shut. One of the gates, however, was not in position; but was somewhat down. He asked the weir-keeper the reason of that, and was told that there was something wrong either with the tripping-bar or the shoe, and he was told that it would be necessary for a diver to go down to put it to rights. Apparently one of the defects of this system was, that those weirs were rather costly to maintain. The weir-keeper informed him of that fact, and M. Boulé confirmed it. It took about fifteen minutes to open Port-à-l'Anglais weir, and about half a day to close all the shutters. Originally at the overfall portion of that weir there used to be a kind of movable counterpoise, in order to adjust the shutter, so that it should adapt itself exactly to the amount of water that was to be brought over, but it had been found that the small weight which was put on was not sufficient to counteract the effect of the rush of water over the weir. Apparently the same kind of weirs as those shown in Plate 3, Figs. 1 and 2, were being put up now in the United States. He had seen the drawings of the Kanawha river weirs, and they appeared to be very similar. The one kind was put over navigable passes, and the other, with a foot-bridge, over overfalls. The next type of weir he would refer to was the drum weir. He went to see the largest, and, he believed, one of the most recent specimens of that type at Joinville, one of the weirs on the Marne, not far from Paris. When he went to see it, some of the paddles were up, some were a little bit inclined, and some were at an angle of 45°. He got the weir-keeper to shut the weir, and he did so by simply opening the sluice-gate in one of the abutments—just turning round a handle, as in the case of an ordinary sluice-gate. He was able, without the slightest difficulty, to close the whole of the weir in a very short time. Then he asked him to open it, and he did that with equal ease, and restored it to the position in which it was at first. He should

say that the opening and the closing of the weir could be done by the weir-keeper in about five minutes. The man seemed to have entire control over the whole weir. Some of the paddles might be standing upright, others a little bit inclined, and he could regulate the discharge over the weir by just a turn, or half a turn, of the handle for turning the sluice-gate. The man seemed to take great pride in working the weir, and certainly it was most satisfactory. He asked him about repairs, and was told that all that was required was to tar the weir once every three or four years, and that no other repairs had been needed since the weir was erected in 1866. One very good plan, which prevailed in France, was to have full-sized models of the parts of each weir on the banks in many cases. They had one at this weir, so that any person who was not acquainted with the working of the weir could see the full-sized model close by. At Port-à-l'Anglais there was a model of the large navigable pass shutter; also a model of the overfall shutter, and of a shutter of the ordinary navigable pass that had been put up some time before, so that, if it was necessary to put in a new piece, it could be made according to the full-sized model on the bank, and was certain to fit exactly. In addition to this, there were at the École des Ponts et Chaussées models of almost all the movable weirs in existence. There was one large room, not quite so large as the hall of that Institution, filled with all sorts of engineering models, and it had occurred to him that it was a pity there was not such a model-room in connection with the Institution of Civil Engineers in this country. He next came to the Port-Villez weir. The history of that weir was curious. Until he went over to Port-Villez, he could not find out what was being done there. It was proposed to erect a weir larger than any other that had ever been erected in France, as it had been decided to increase the navigable depth on the Seine from 6 feet 6 inches to 9 feet 9 inches. It was, therefore, necessary to erect some new weirs on the Seine, and Port-Villez was one of the places chosen. The French engineers had never made the ordinary frame-weir nearly as large as the height proposed, and so they began to think what other weir they could adopt. M. Krantz was ready with his pontoon weir, saying that it was capable of being used for much greater heights than had ever been used before. It was therefore determined to try it. In France the Government paid for the erection of weirs on the rivers, and therefore naturally enough it was not very difficult to get experiments tried, as, if successful, the experience gained might be utilised throughout the country. The weir was commenced at

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Mr. Vernon-Harcourt. Port-Villez; but, as it was a new system, it was thought better to experiment upon it first, as he had mentioned in the Paper, at Bougival. It did not, however, prove a great success; it did not work with that nicety that was desirable, and seemed to require a greater pressure of water than would be got by the mere difference of level between the upper and lower water. At last it was decided to abandon that system, and, having no other system particularly to recommend in its place, the French resolved to go back to the old frame weir. But they wanted a very much larger frame than at Suresnes, Martot, or Bezons. The height of the Martot weir was about 11 feet, but the Port-Villez weir had a total height, from the top to the bottom, of 18 feet. That, of course, necessitated a considerable increase in the size of the needles, but as they were not quite certain whether they would use needles or other means of shutting the weir, they determined to strengthen the frames so that they might be suitable for needles or any other form of barrier. In using needles it was only necessary to make the frames capable of resisting the pressure on the top bar, because the needles abutted against the sill and against the top bar, and did not touch the other part of the frame; but in the case of a hinged shutter, such as was put up at Port-Villez, it was necessary to have the frame strengthened, so as to be able to bear the pressure of the water all down the front. In consequence of their having not settled what sort of barrier they would employ, they made it stronger than it otherwise would have been—strong at the top, and strong all the way down. Not having settled whether they would use large needles or other arrangements, they made provision for needles on the sill. It might be imagined that it was rather a bold notion, to think of putting up needles for such a height. The size of the Suresnes needles was 3 inches square; but the needle that was considered to be necessary for the Port-Villez weir was 8 inches square. Provision was made for needles there, without any arrangement having been devised for putting down the needles or raising them; and when it was remembered that the needles at Suresnes were about the greatest weight a man could carry, it would be imagined that a needle of that scantling, and much greater length, would be impossible to manage. Naturally enough, the French engineers began to consider by what other method they could close this weir. M. Boulé had designed an arrangement which he tried at Port-à-l'Anglais. He put some panels along the Port-à-l'Anglais foot-bridge, of which a description was given in the Paper, and by this means he was able to use a much smaller scantling of timber

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than if he had used needles. M. Boulé found this quite successful, and proposed it for the Port-Villez weir, but it was thought that another system would be better. In the meantime, the Russians were putting up a somewhat similar weir on the Moskva, at Moscow, and they were rather in a difficulty. They proposed to have needles 7 inches square, but they did not know how to manage with such large needles. They heard of M. Boulé's panels, but the arrangement they adopted was somewhat different. The frames were very light, and calculated only to resist the strain at the level of the top bar against which the needles were to rest, and were not suited to support the pressure that a series of panels would bring upon them. The arrangements they adopted were these. They put a needle down opposite each frame, and they formed grooves in front of each needle; and they slipped planks of timber down the grooves with little projecting pegs, by which they could lift them up. They were able by that means to keep the strains on the place where the frames were designed to support them, and they were able to do away with the trouble of using these very large needles. He ought to mention that the frames and hinged shutter adopted at Port-Villez were as shown on Plate 4, which he had made from a drawing kindly given him by M. Caméré, and that was the weir as he had seen it. He was fortunate enough to see one of the series of frames in place before the cofferdams were removed. He was therefore able to see the whole set of frames from top to bottom. The other bays had been finished, and this set of frames was just finished, the water was shortly to be let in, and the cofferdams to be removed. There was one other matter he would like to mention, and that was that another weir was going to be erected at Poses, below Vernon. It was to be of greater height than any of the weirs hitherto erected on the Seine. In the case of the Poses weir it was arranged that, instead of having movable frames all the way along, as at Port-Villez, there should be piers 100 feet apart. There were to be seven openings altogether; and over these girders were to be placed which would carry the foot-bridge. Uprights were to be hinged to the girders, and against these uprights the hinged shutters were to be placed. These uprights hung down, when in place, as shown on Fig. 1 (see next page). They rested against the sill at the bottom, and they were hinged to the girder, so that when desirable they could be lifted up, and rest in a horizontal position. Therefore the whole of the framework of the weir could be placed entirely out of the water. The drawings had been completed for this weir at Poses, and the work had been commenced. It was 3 feet 3 inches higher than that

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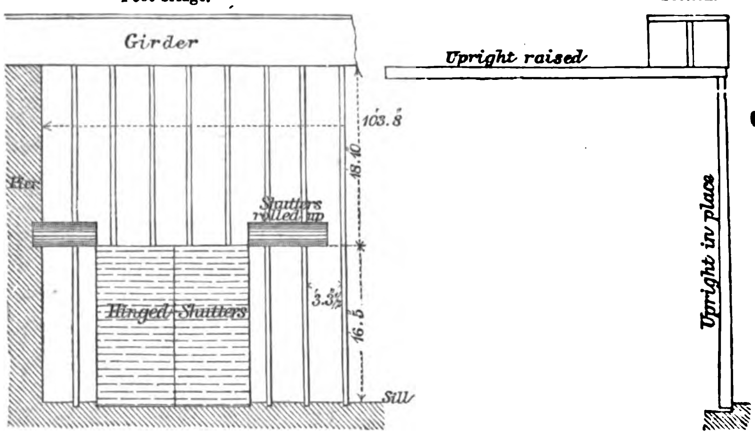
at Port-Villez, but it was a question whether its cost would not hinder its adoption in other weirs on the same river. This type of weir appeared to have been thought of by the late M. Tavernier, engineer-in-chief on the Rhone, where the boulders brought down by that river rendered the raising of frames difficult, and where consequently it was very desirable to be able to lift all the fragile portions of a weir out of the river in flood time; but the employment of movable frame weirs on the Seine were not open to these objections, and hitherto had fully answered their purpose. The cost of different weirs as given him by M. Boulé was as follows, for a height of weir of 13 feet above the sill: the needle weir, £61 per lineal foot; the shutter weir, £73; the pontoon weir,

Fig. 1.



£147 to £158; and it was estimated that this new weir of M. Caméré would cost about the same as the pontoon weir.

Mr. Buckley.

Mr. R. B. Buckley did not wish to add anything to his own Paper, but to make a few remarks on Mr. Vernon-Harcourt's. That Paper was one of great interest to all engineers connected with hydraulic works, and especially interesting to himself, since his experience in India had been mostly in connection with weirs and other works dealing with water. Last summer he had an opportunity of visiting all the weirs that Mr. Vernon-Harcourt had described, except the Krantz weir (which he believed had been removed, wherever it was erected), and the bear trap, which, as Mr. Vernon-Harcourt had said, had almost become obsolete. The first part of the Paper described the general construction of weirs,

Mr. Buckley.

and opened out considerations on which he should like to make some remarks; but as the real discussion before the meeting was in regard to movable weirs, he would only make one observation upon the first part of the Paper; that would be with reference to the oblique weirs. Mr. Vernon-Harcourt stated: "The tendency of oblique weirs, like those referred to, is to divert the strongest stream, and consequently the deepest channel, towards the bank on which the upper end of the oblique weir is situated." It was no doubt quite true that, in rivers where a good foundation could be obtained, there would be very little objection to oblique weirs; but in rivers such as those which had to be dealt with in India, with sandy beds, and difficult foundations, they were very objectionable, for three reasons. First of all, they induced currents parallel to the weir; secondly, they caused a deepening of the channel above the weir, near the up-stream end, which was often dangerous; and, thirdly, they raised the level of the water in the river at the lower end of the weir. There was a remarkable instance of this in a weir constructed by General Rundall. There happened to be, near the site where that weir was to be erected, an old stone causeway built diagonally across the river, used, when the river was low, as a crossing for bullock carts. General Rundall thought it would be an advantage to use that roadway for the toe of the slope of the weir, and consequently he put the weir at a considerable angle to the stream. The weir was undermined more than once in consequence of the parallel channels induced, and General Rundall said, "The water piled up against the left wing so much, that, in full flood, there was a plunge of 2 feet over it, while in the other flank no sign of any obstruction was visible." It was hardly necessary to point out what great danger there was with a depth of 2 feet of water over the top of the wing of a weir across a river with a volume of 700,000 cubic feet of water per second. This weir was across the river Katjoree in Orissa; it was 1,200 yards long, the crest was 12 feet above the river bed, the rise of the river in flood was 30 feet, that was 18 feet above the crest of the weir. The work was ultimately made safe against the action of the parallel currents by throwing in large quantities of rubble stone in front of the weir. Oblique weirs had been advantageously made in India in rivers with boulder beds.

At the head of the Jumna canal the river had a declivity of 15 feet per mile, and the bed consisted of large boulders, which in the flood season came down with immense velocity, and were very dangerous things to have to deal with. In this river in the dry season the water meandered among the boulders in such

Mr. Buckley. a way that it was most difficult to draw it into canals. For this reason the weir was made oblique to the stream, by which during floods a heavy stream was brought to the lower side where sluices were placed, so that a deep channel was formed which led the water to the canal.

A list had been given by Mr. Vernon-Harcourt of five different kinds of weirs in France. Mr. Buckley was sorry to see that one of the most modern, and in some respects, he thought, the best, had been omitted from the list. It was casually referred to as M. Girard's system, and it was mentioned that "this contrivance was tried at the overfall of Brûlée Island weir." That would lead persons to suppose that only an experiment had been made with it, whereas the fact was that it had been permanently constructed and was extremely successful. On one bank there was a lock which, during high floods, might be entirely submerged; next the lock there was the "Navigable Pass," which in this weir was 98 feet long, and beyond that was the "Déversoir," or regulating weir, 82 feet long. During floods the water-line would be above the top of the lock walls, all the shutters of the weir would be open, and boats would pass freely over the weir. The floor of the "Navigable Pass" was level with the sill of the lock, the crest of the regulating weir being 3 feet 4 inches higher. Where the weir was entirely open, and the discharge of the river was such that it gave a sufficient depth of water over the "Navigable Pass" to enable boats to pass, the lock was not used, and the navigation was worked through the pass. When the river was low it would be necessary to impound the water, the shutters of the weir would be up, and the lock would be used for passing the boats. The shutters of the "Navigable Pass" were of the ordinary Chanoine type, as described by Mr. Vernon-Harcourt. The regulating weir was of stone, the face being ashlar and the heart rubble. The down-stream face of the weir was sloped at an angle of 30° with the floor. The shutters of this weir were of wood, 11 feet 6½ inches long by 6 feet 1½ inch high; they were hinged on a horizontal axis to cast-iron bearing blocks, which were firmly embedded in the crest of the weir. On the sloping face of the weir hydraulic cylinders were fixed. A small copper pipe 1 inch in diameter led from the bottom of each of these cylinders, through a trough, which was cut in the masonry of the weir, to an accumulator in an engine-house on the abutment of the weir. There were seven shutters on the weir; each shutter was fitted with a hydraulic press. The plunger of each of these presses had, at its head, a cast-iron cross-head, about 4 feet long, which worked in three cast-iron guide-

plates fastened to the slope of the weir. This cross-head was connected by three connecting rods to a horizontal axis on the back of the shutter at about half its height. That weir had been at work, he thought, for six or seven years most successfully, and he saw it at work the other day in France. Each shutter when down was horizontal: at the point where each shutter met its neighbour there was a stone pier built out into the river below; grooves were cut in the piers so that baulks of timber could be dropped into the grooves, if necessary, and the bay being pumped out, the hydraulic presses could be examined and repaired. Mr. Buckley.

The weir was worked in this way. On the bank at the side a small house was fitted with a turbine, which was driven by the head of water of the weir. This turbine worked a double-action water-pump and a single-action air-pump. In that house there was a cast-iron accumulator, 24 inches internal diameter, 2 inches thick, and 11 feet high. The turbine was put to work, and the air-pump first of all pumped the air in until there was a pressure of 170 lbs. on the inch. Then water was pumped into the accumulator until a pressure was obtained of 350 lbs. on the inch. There was then accumulated sufficient force to lift up all the shutters on the weir in about five minutes. From the accumulator a separate copper pipe led to each hydraulic press. Each of those pipes was fitted, in the engine-room on the bank of the river, with a small cock, so that at any time any one of the seven shutters could be placed in communication with the accumulator, or with the waste water tank, which was in the same house. The man in charge of the weir could, therefore, when his accumulator was charged, either lower all the shutters at once, by simply putting the pipes into communication with the tank in the engine-room, or let any one down, or lift one up, or raise one and lower one at the same time. It was very interesting to see the man with a small spanner, which could be put in a waistcoat pocket, raise or lower any of the shutters against a head of 6 feet 1½ inch of water.

The shutters were kept in position by the hydraulic pressure on the piston. It struck him that there must be some leakage, and he enquired from the keeper whether that was not so, and whether he had not constantly to keep pressure on the accumulator in order to replenish any press that might leak. The lock-keeper said that was not so at all—that practically there was not the slightest leakage—that they had feared there would be, but that there was not. It also seemed to him, when he was there, that there would be considerable danger from frosts—that if severe frosts were to occur, probably the hydraulic cylinders would burst, or the pipes

Mr. Buckley. would burst, or the water get frozen up. He had received a letter from an engineer resident on the spot, which, with the permission of the meeting, he would read presently. He would mention, first, that the presses were purposely below the level of the weir, and were always kept under water, so that the frost did not have an opportunity of exerting its whole force upon them. He should certainly have supposed that in the late frost some accident might have been anticipated, but that was not the case. In a letter from an engineer close to where the weir was erected, it was stated that the frost was − 25° Centigrade, or 13° below zero, Fahrenheit.

The engineer to whom he had referred, M. Lavoinne, wrote, "No accident whatever occurred out of the engine house; viz., in the cylinder connected with the shutters, or in the conduits bringing the water-pressure to them, during the very hard frosts we had here (− 25° Celsius). In the engine room only, on account of insufficient heating, two feed pumps, which should have been emptied, and a pipe connecting the reservoir with the hydraulic presses, were broken by the frost because of the neglect of the engineman. The opinion of the superintendent is that with more care and better efficiency of the heating apparatus, no damage should have occurred. The cost of the repairs, consisting of the replacement of the broken cylinders and pipe, was not over 500 francs; the whole system was again in order within two weeks." He believed that the weir at the Isle Brûlée was the only one in the world constructed on that system.

The bear-trap system had, he thought, been given over. Some improvements were proposed upon it, but perhaps it was hardly worth while referring to them, as they were never put into practice. M. Poirée's weir had these great advantages. It was, he believed, the cheapest of all the systems which had been invented. It was very much used in France, and was the simplest of all the systems, the most easily repaired, and did not bring such a heavy strain on one part of the apron when it was removed as M. Chanoine's system. In the latter system one shutter must be let down first, and the shock with a head of 10 feet of water brought a heavy strain on the apron, which sometimes yielded. M. Poirée's system let the water through gradually, but it had this disadvantage, which had not been alluded to in the Paper—that the frames, when they were lowered down on to the floor, as they were when the weir was entirely open, were liable to get caught by anchors or boats, and to damage from those causes. The system at Port-Villez was no doubt an excellent one, but he was not aware

that it had been adopted. It had always surprised him that something of the same kind had not been used on those weirs after the fashion of Venetian blinds. He thought it would be easy to make a rolling shutter to go down the frames, with bars some few inches wide, which might at first be kept horizontal so that there would be no pressure on them; these bars might be hinged on horizontal axes, and gradually turned with their flat faces to the stream, as it was required to diminish the discharge. M. Chanoine's system had been used in various parts of the world, and in one instance in India. It had the great advantage over M. Poirée's system that, when it was down, all the moving parts were hidden by the shutters, so that there was no danger of their being caught by anchors or boats, or anything else that might pass. Mr. Buckley.

All the systems of weirs that had been described in Mr. Vernon-Harcourt's Paper had this disadvantage—that they could only be erected against comparatively small heads of water. He had a list of the maximum heads against which the Chanoine weirs had been erected, and he believed that on the average the greatest head against which the last shutter had been lifted was 3 feet 6 inches. These systems were not applicable to cases such as occurred in India, where a shutter had to be lifted against a head of 10 feet of water. The drum weir was no doubt an extremely ingenious and beautiful appliance. He had seen it at work in France, as Mr. Vernon-Harcourt had described, with one shutter erect, another down, and the others at different angles, but he did not understand how that arrangement was obtained. One point in connection with this form of weir had not been prominently brought forward in the Paper, namely, that each of the paddles was divided from its neighbour below the surface of the weir by a diaphragm. The aperture marked there was the hole which was cut in the diaphragm, so that each of the lower paddles when it turned fitted almost watertight against the diaphragms. The apertures which were cut through the diaphragms, one above and one below the paddle, were connected in the abutment or pier with culverts worked with sluices. The construction of those culverts was somewhat complicated, and he did not think it necessary to explain it. It was quite easy to understand that when the water in the upper portion of the trunk was in communication with the higher level, and when the water in the lower portion of the trunk was in communication with the lower level, considerably below the crest of the weir, and when the shutter was in a horizontal position, it would assume an upright position. It was

Mr. Buckley. equally easy to understand that when the lower aperture was put in connection with the greater head, and the upper one in connection with the lesser head, the pressure would turn the paddle round and bring the shutter down into a horizontal position; but he did not think it was easy to understand how, when there were six or eight of these shutters in one line, there could be any arrangement for admitting the water into this or that tube, so that one shutter would fall, the next would be at an intermediate angle, and the third perhaps right down. Surely, whatever the condition of affairs might be, the pressure must be uniform throughout the whole length of the shutters connected with the same sluice. Why, then, should one shutter stand upright, the next one fall down flat, the third be at an angle, and the fourth upright again? He knew it was so, because he had seen it himself, but he did not understand it, and he should be glad if Mr. Vernon-Harcourt would explain it. In the Noisiel weir, to which Mr. Buckley particularly referred, it was not the case that there was any communication from the abutment to the pier, but it was worked entirely from the pier, from one end only of the weir.

The system of pontoon weirs of M. Krantz was tried, he believed, in France, but when he was over there he was told that it had been removed, not having been found applicable. The most general systems of French weirs were Poirée's and Chanoine's, which were used in 60 per cent. of the weirs in France. The next was that of Desfontaines, the drum weir, which was also considerably used, but that system was only suitable for overfalls, as the portion below the crest had to be about one half as deep again as the head of water on the weir. M. Girard's system appeared to him not only applicable to the regulating weir but also to a navigable pass. There was no reason why the hydraulic presses should be inclined at an angle. They might be laid horizontally on the floor: it was only necessary to lay them sufficiently below the water to keep them from frost. The system was excellent, and for large discharges in Indian weirs would certainly be a good one.

With reference to the cost of the different systems of weirs on French rivers he wished to give the following Table, which he had prepared from the French works on these weirs. He thought that the method of comparison by superficial foot of shutter was in some respects more likely to be useful than by lineal foot of weir.

Mr. Buckley.

System.	Height of Shutters.	Approximate Cost per Lineal Foot of Weir.		Approximate Cost per Superficial Foot of Shutter.	
		Including Foundations.	Movable Part only.	Including Foundations.	Movable Part only.
	Feet. Inches.	£. s.	£. s.	£. s. d.	£. s. d.
Poirée or Boulé . . .	13 1½	46 7	..	3 10 7	..
Chanoine	10 0	39 0	10 0	3 18 0	1 0 0
Girard	6 5½	38 2	25 8	5 18 0	3 18 8
Krantz	9 10	82 10	..	8 7 10	..
Desfontaines, or Drum weir	2 10	29 0	10 0	10 4 2	3 10 5
American, or Bear trap.	8 10	101 0	..	11 8 8	..
Vanne of M. Poirée . .	..	..	21 16	..	..

He agreed with Mr. Vernon-Harcourt that while embanking rivers might be a good plan, dredging their beds was better.

Mr. Wells.

Mr. L. B. Wells said the navigation of which he was engineer was so small, compared with the large rivers to which reference had been made in the Papers, that he felt reluctant to trespass upon the time of the members by referring to it; but, as the trade carried on it was an important one, and the trustees of the river Weaver had, during the last few years, spent a considerable sum of money in improving their navigation, he had therefore thought it his duty, as a Member of the Institution, to endeavour to be present at the discussion. The level of the pond on the Weaver, communicating with the tidal waters of the Mersey, was 16 feet 6 inches below Northwich pond, on which a great deal of salt was made, and that difference of 16 feet 6 inches was pretty evenly divided between four weirs and four locks. Some years ago it was determined to build more capacious locks to facilitate towing in train as now largely practised on the Weaver, and also to accommodate coasters; and at the same time it was decided to build two sets of locks, one set to take the place of two sets of the older ones. In the first instance the water was raised readily by placing a fixed weir across the flood course at a short distance below the weir holding up the water for the Northwich pond, the pond raised being almost entirely a canal, and consequently no drains were interfered with, nor was the flood discharge of the river affected. This was suggested by Mr. E. Leader Williams, M. Inst. C.E., when engineer for the Weaver, the work being carried out and the locks commenced by his successor, Mr. J. W. Sandeman, M. Inst. C.E. But in the second instance the locks were placed at the lower end,

Mr. Wells. near the fourth weir from Northwich; and had that weir been raised, as it was a fixed weir with small side sluices, a dam of 4 feet 3 inches would have been thrown across the river 1¾ mile below the present discharge at the same level. He considered that would be impolitic, as rendering the trustees liable to litigation; moreover the foundations of the old weir were not sufficient to warrant the rise; he therefore recommended the trustees, as it was absolutely necessary to raise the water, to do so by means of sluices which could be lifted clear of the river in flood time, and so leave the waterway unobstructed. The proposal was submitted to their consulting engineer, Sir John Hawkshaw, Past-President, who expressed his approval of it. The sluices, eight in number, 15 feet wide and 13 feet deep, were now in course of construction; they would be fixed in the valley a short distance above the Dutton viaduct of the London and North Western railway. He thought that if the bed of the river was cleared of all obstructions at that point, and the two existing weirs were removed, no land or property owner on the navigation could have any cause of complaint. While greatly admiring the ingenuity displayed by engineers in France and India in dealing with the rivers in the methods described, still he felt bound to state that he should not feel satisfied to trust the trade of the Weaver to works of so light a character. During the past twelve months he had raised the water in five of the ponds of the Weaver navigation by means of movable caps. In May last the chief carriers on the Weaver, who were also makers of salt, and owners of the craft (locally flats) that conveyed it to Liverpool, had a conference with the trustees, and made a very strong representation that the navigable depth should be increased from 8 feet to 10 feet, and that this should be done for the trade of the coming summer. It was also decided that the river should be run off in the middle of July to enable the midfeather of one of the old locks to be removed, and for other purposes. He demurred at the haste with which the work was required to be done, but his objection was overruled. He at once set to work, and, with the help of Mr. W. H. Hunter, who aided him very materially, in a fortnight plans were prepared and the work was ordered to be proceeded with. It was necessary to raise the water on the sills of five locks. One of the locks would be removed when the large sluices at Dutton, to which he had referred, came into operation, and the weirs in that case were only partially capped; in the others the whole width of the weir, about 75 feet, was covered by three movable caps of equal length. The weirs, with one exception, had fixed

wooden caps varying from 6 inches to 16 inches in depth; these were incorporated with the movable caps, and as the stone crest of the weir was lowered 5 inches, a very considerable improvement in the flow of water was obtained. Owing to the difference in depth required over the several lock sills, the height of the caps varied from 1 foot 11 inches, to 3 feet 2 inches. They were formed of iron beams properly braced and green-heart planking—a number of short lengths from the old lockgates being available. The sills were of green-heart, and the cap was of pitch-pine. There was a light overhead bridge, formed of rolled iron beams, resting upon masonry, on the banks, and on cast-iron columns on the weir-head; this also supported two semicircular brackets, through which the lifting screws worked. The lifting screws, two to each cap, were 2½ inches in diameter, and, to lessen friction, four cast-iron rollers on turned wrought-iron axles were bolted to each corner of the caps. The caps were spaced 4 inches apart, and the joint made by a wooden stop water hinged at the bottom, closed by the water-pressure and opened from the bridge. At the top of the bracket attached to the screw-nut were wrought-iron arms, supporting light cast-iron rims: over these a pitch chain was carried, so that the two screws worked simultaneously. The caps, which had been in operation about six months, had worked remarkably well. They were made in the shops of the trustees, and were fixed on the weirs, and workable at the end of the stoppage, July 31st, two months after date of order. Their cost was about £3 per lineal foot. No doubt it would have been considerably less but for the haste with which the materials were bought, and the work was done. The caps enabled the water to be let off in flood time, and maintained an increased depth under ordinary circumstances, and, as the Weaver craft carried about 3 tons to the inch, this was of considerable importance to the owners. A large barge had already been built to carry from 360 tons to 400 tons, whereas 250 tons previously constituted an exceptionally large cargo. Mr. Wells.

The question of sluices being, in his opinion, so much akin to that of movable weirs, especially in rivers where the traffic could not be navigated along the flood course, he thought this a proper occasion to mention an experimental sluice which he had constructed twelve months ago, to try the effect of rollers as a means of lessening friction, and also to see if the joint between sluice and post could not be made by water-pressure in front as readily as at the back of the sluice. The sluice in question had a clear width of 9 feet 4 inches, and the ordinary head of water was 4 feet 6 inches; the sill being uncovered every opportunity was afforded

Mr. Wells. for examination. No special trouble was taken. Four rollers 7 inches in diameter and 3 inches wide were found in the yard, the axles were not turned and the rollers were fixed in brackets bolted to the side uprights of the sluice. When in place, a Duckham's weighing machine was attached to the sluice, and to a block and fall, the end of the fall being taken to a crab. The sluice weighed 1 ton 15 cwt. Water was then let in through the cofferdam and rose to 4 feet 6 inches above the sill. This gave an area of pressure of 42 square feet.

Mean pressure . . .	2·25 feet ×	62·4 lbs. =	140·4 lbs.	
Total pressure . . .	42 „ ×	140·4 „ =	5,846 „ =	2·63 tons.

The sluice was started when a pressure of 1 ton 19 cwt. was registered by the weighing machine, or 5 cwt. more than the dead weight of the sluice. The coefficient of friction was therefore ·095. To close the vertical joints, a stopwater of oak, 5 inches square, loaded to the specific gravity of water, truly planed on two adjacent sides, was attached by a bolt, on which the stopwater hung loosely, to the front edge of the sluice; a width of 5 inches of the edge of the sluice was planed and also of the side in way of the stopwater, so that there were four contiguous smooth surfaces; the pressure of water kept these in contact, and an excellent watertight joint was made. There existed in his office a correspondence between Mr. Sandeman and Mr. F. G. M. Stoney, and the latter gentleman had prepared plans for the Dutton sluices. Mr. Stoney proposed longer spans, and to work the sluices on a system of free rollers, of which he was the patentee, and which was a very ingenious invention; but for reasons which need not be entered upon his plans were not adopted. Having been in the habit of using wheels for heavy doors on land, and in general seeing rollers employed to lessen friction, Mr. Wells had taken an early opportunity of testing their use for sluices, up to the present time with undoubted success; and he saw less reason to apprehend difficulty in working rollers than in working the screws with which so many sluices were lifted.

Mr. Parkes. Mr. W. Parkes said his object in rising was to take exception to a small portion of Mr. Vernon-Harcourt's Paper. He hoped in doing so that it would not be thought that he did not appreciate the great care and industry which that gentleman had displayed in collecting so much interesting information, which he believed would be of great use to those engineers whose duty led them to adopt a system of movable weirs in rivers. But when, some weeks ago, he saw the notice of Mr. Vernon-Harcourt's Paper on "Fixed

and Movable Weirs," he had hoped to have a valuable contribution to a question which had never yet been properly solved, namely, the theory of fixed weirs in rivers. When the Paper came into his hands he was disappointed to find that that question, which he regarded as one of great importance, was treated in a very cursory manner. Indeed, he thought that to treat a question in that way was really doing a mischief to the practice of the profession. If any engineer who was several years younger than himself were to take up Mr. Vernon-Harcourt's Paper as an authority, and a very high authority it would be as coming from that gentleman, as to how rivers should be treated, he would come to the conclusion that the system of fixed weirs had been by general consent regarded with indifference, if not condemned. He could not admit that that was the case. The Paper alluded to the case of the Severn. That matter had been discussed a great deal many years ago, but so many years ago that many gentlemen present could remember nothing about it; and therefore he thought he might profitably occupy a little time in giving a short sketch of what really did occur. He believed he should succeed in showing that the question was of much more importance than any person would be led to suppose from the way in which Mr. Vernon-Harcourt had treated it. Mr. Parkes.

In the year 1841 the River Severn Commissioners applied to Parliament for power to improve about 42 miles of the river for the purposes of navigation. The engineer whom they employed was the late Mr. (afterwards Sir William) Cubitt, then a Vice-President of the Institution and a man of the highest eminence. The plan which he proposed was to put in the river five solid weirs, which would be placed obliquely to the stream, and alongside each weir a lock in a side cut to accommodate the navigation. That was to give about 6 feet navigable depth throughout that length of river. Mr. Cubitt contended that the placing of those weirs in the river would not interfere with the discharge of flood-waters, and he stated that the great virtue of his weirs was their length, which enabled the water to pass in a thin film over a considerably greater length than the ordinary breadth of the river. He made it from two and a half to three times the breadth of the river, and he obtained that length by putting the weirs obliquely in the stream. But he asserted there was another advantage in the obliquity of the weirs. When the water rose to such a height that at the lower side of the weir its level was nearly equal to the level at the upper side, the current then pursued its course downwards parallel to the general line of the stream, and did not fall over the weir.

Mr. Parkes. In that case, Mr. Cubitt contended that the obstruction caused by the weir was simply the cross-section of the weir itself in a line at right angles with the stream. If a cross-section of the river about the middle of the weir was taken there would be first a dip down to the natural bed of the river; then the weir and rise over that, and then the natural bed again. Thus there would be the natural section of the river with an erection in the middle, which Mr. Cubitt said was the only obstruction, and this obstruction he contended could be compensated for by giving some extra width to the river at that spot. This theory was very much contested. It was not altogether the essence of Mr. Cubitt's scheme, because he said that his main point was the great length of the weir. That was the evidence which Mr. Cubitt gave to the Parliamentary Committee.

The Gloucester and Berkeley Canal Company employed another engineer of equal eminence—the late Mr. James Walker—and many then present might know that he, Mr. Parkes, was a faithful though unworthy disciple of that eminent engineer, and all his personal sympathies were with the cause which that gentleman espoused. He should now, however, show that in this particular case he thought Mr. Walker was mistaken. Mr. Walker objected altogether to the lowest of Mr. Cubitt's five weirs, and proposed an alternative plan of improvement, preferring that for the lower 10 miles the river should be treated as a free stream, merely equalising the section throughout, so as to give uniform slope and depth. Then for the upper 12 miles, he agreed that they should be treated by means of locks and weirs. But he wished to put into the stream a system of movable weirs, which were designed in very great detail, and no doubt if carried out would have furnished material for another chapter in Mr. Vernon-Harcourt's Paper. But it was not carried out. Mr. Walker objected most strongly to Mr. Cubitt's theory of the weir being only an obstruction to the extent of its cross-section at right angles to the stream. He maintained that the weir offered an obstruction to the flood waters equal to the breadth of the river multiplied by the height of the weir, whether the weir were placed directly or obliquely to the stream. If he might be permitted to do so, he would read Mr. Walker's own description of his views on the matter. In a Report which he addressed to the Gloucester and Berkeley Canal Company in 1841 he stated, "There is, I think, no doubt that placing solid dams at intervals across the stream, whether directly or obliquely, and from 5 to 11 feet above the present bottom of the river, will diminish the velocity of that portion of the water which

is below the level of the weirs, and near them, and of the whole descending column for a very considerable way up the river; and that in this length so interfered with, particularly near the weirs, first the water will be kept back, then a deposit will take place, which will diminish the depth, and therefore raise the surface of the water and increase the floods." That was Mr. Walker's opinion with regard to these solid weirs, whether direct or oblique. In the evidence that he gave before the Committee in the same year he was asked whether, supposing Mr. Cubitt's plans were followed, and it was found that they did not answer, would the damage be anything more than the expense of building them and taking them down again? His reply was, "The river would have found itself a new regimen; the river would be in steps in place of being in an inclined plane. Every weir you put in makes a step in the river, and if you were to go back again, and make it an open river, you would have to remove all the shoals formed at the back of the weirs. I think the expense of doing that would be immense." That showed that Mr. Walker's opinion was very strongly opposed to solid weirs in the Severn, upon two grounds, First, that they would interfere with the free passage of the flood-water; and secondly, that they would form deposits up stream. He failed to persuade the Committee of this with regard to four out of the five weirs. Those were sanctioned to be carried out on Mr. Cubitt's plan; but with regard to the fifth and the 10 miles of river dependent upon it, Mr. Walker's plan was ordered to be carried out—that of regulating the river, and reducing it to a uniform section. These works were shortly afterwards commenced, under Mr. Cubitt's superintendence, by Mr. Leader Williams, the engineer of the Severn Commission. In the year 1845 Mr. Williams presented the Paper to the Institution of Civil Engineers, which was alluded to in Mr. Vernon-Harcourt's Paper, giving a description of the works. He there stated that the locks and weirs were completed and in successful action; but the 10 miles to be dealt with by Mr. Walker's plan had not been completed, and he promised a further communication with regard to it. He would now read what Mr. Williams stated with regard to the effect of those weirs: "At Holt, an old barge, which had been laid up as useless by the contractors, got adrift and sunk in 10 feet water, 20 yards above the weir. It continued undisturbed during the short-water season; but the first heavy fresh raised it from the bottom, and laid it upon the upper sill, there not being sufficient water to carry it over. Another proof of the uninterrupted action of the under-current is, that the bottom of the channel, immediately above the

Mr. Parkes.

Mr. Parkes. weirs, not only maintained its original depth, but has been scoured out, in some instances, to a depth of 2 feet." It was therefore evident that two or three years after the works had been completed there was nothing of the evil which Mr. Walker had anticipated. In place of the accumulation which he expected to find there was actually a deepening, and this barge was brought up by the flood and carried away to the weir.

Shortly after, the Severn Commissioners found that, according to their judgment, the works which they were carrying on, on the system recommended by Mr. Walker, were likely to turn out a complete failure. They therefore applied to Parliament again for power to make another lock and weir, not in the spot formerly chosen, but 4 miles further down the river, at Tewkesbury. In the year 1851, Mr. Walker was employed by the Admiralty to report upon that, and Mr. Parkes was associated with him in that Report. They went over the river and examined it very minutely. The result of Mr. Walker's investigation was that he was of opinion that his plan for equalising the river had not been so far fairly treated. He therefore recommended that it should be persevered with, and he showed wherein it had not been fairly dealt with. This was simply incidental, but the portion of Mr. Walker's conclusion important for the present discussion was this. It was contained in his report to the Admiralty, dated the 1st of September, 1851: "I think it right to say of the locks and weirs and other improvements in the river between Worcester and Stourport, that they appear to give general satisfaction as respects the passage of the trade, without prejudicing the drainage of the country that is within their scope." Now, considering the opinion that Mr. Walker had given ten years previously, that was a very remarkable admission. It was as much as to say that he had changed his mind about the action of these weirs, and that they were, after all, a success, and Mr. Parkes felt bound to confess for his own part that he also considered they were a very great success.

The Admiralty were not persuaded by Mr. Walker to carry on their opposition to the lock and weir at Tewkesbury any further, and the Commissioners were allowed to carry out the works. There was some little delay about doing it, and not until 1860 did Mr. Leader Williams present another Paper to the Institution. In that Paper Mr. Williams gave a fresh description of the effect of the locks and weirs, which, if the meeting would permit, he would read. This was in 1860. "On comparing the original section of the river, made in 1842, before the weirs were erected, with a series of transverse soundings taken at

16 feet from the head of the weir, it was found, that the depth of the channel had been actually increased 3 feet to 5 feet. On taking longitudinal soundings 1½ mile up the river, it was again found, that the depth had been increased the whole distance 3 feet to 5 feet. The same effect had been produced in the whole of the pools between the weirs; the channel, indeed, was deepened to such an extent, that the banks which had stood for many years previously, had, in some places, fallen in, from the increased energy of the current having scoured out the bottom." This was some fifteen or sixteen years after the weirs were erected, and surely there was plenty of time during that interval for the anticipated deposit to have taken place, if there had been any tendency towards it. But the tendency was evidently in quite an opposite direction—namely, to scour out the river. To what could that scouring be attributed except to the erection of the weirs, which were the only artificial works made in the Severn? That, however, did not seem to have been the opinion of some engineers at that time, for on the very same evening Mr. Bidder, who was then in the chair, made these remarks: "He could not believe, that all the facts connected with the works of the Severn had been detailed, because, so far as he understood the results, they had been produced without adequate causes." That rather reminded him of the man who said: "If your facts do not agree with my theory, so much the worse for your facts." Mr. Parkes preferred to think that the facts spoke for themselves, and if theories did not account for those facts, engineers must try and improve their theories. For his own part, he confessed he was not able to satisfy himself entirely how such a remarkable result was attained, but he could not fail the less to admit that it was attained, and that in some way which must be attributed to the weirs, and to some extent, he thought, to the oblique position of the weirs. Now it really appeared to him that Mr. Vernon-Harcourt had something of the same notion as Mr. Bidder, for he said, "The merit claimed for these weirs, of actually increasing the rate of discharge, and diminishing damage from floods, is inadmissible." He submitted most respectfully that that statement required proof. In a Paper on fixed weirs, it was hardly fair to make such an assertion as that, and leave the proof to the imagination. The facts were undoubted, and to what but the increased capacity of the river could they be due? If so, the floods must have a freer discharge than previously. Mr. Cubitt made no claim for an improved flood discharge. He only contended that it would not be lessened. The claim for improve-

Mr. Parkes.

Mr. Parkes. ment was a subsequent one, based on actual experience of the results obtained. Now, what were the grounds on which this claim was based? Mr. Parkes gave only a negative value to the evidence of landowners that the flooding of lands was reduced. There was no good standard of comparison except in a long series of years, and he would only assume that it was proved the floods were not aggravated. The one important and definite fact established was the deepening and enlargement of the river channel itself. He conceived this could be accounted for only by an increased scouring power. As a rule the scouring power of a river channel was the land floods, but a given volume of flood water would be more or less effective as a scouring agent according to circumstances. If it were thrown into the river with such rapidity that the channel was unable to carry it off, it would overflow on to the adjoining lands, and there, by evaporation, absorption, escape by by-channels, and retardation of escape into the river channel, much of the scouring power would be wasted. Hence, anything that facilitated the immediate passage of the flood waters by the river channel increased the proportion of those which were effective for scour. This was what was done by the pounded river. The disturbance caused by the sudden accession of water at any spot would be transferred down the course of the channel with a velocity depending on the square root of the depth of water in the channel, and therefore far more rapidly in the pounded than in the unpounded channel. Thus the escape of the flood by the channel was facilitated, and the rise above the banks was retarded, in some cases it might be even altogether prevented, and thus the water was kept flowing in the defined channel for a longer period under conditions favourable for scour. Of course it was an essential condition that the weir itself should have a capacity of discharge at least equal to that of the channel above and below; but this was assumed to be provided for by length of weir while it acted as an overfall, and by width of channel above the top of the weir when it was "drowned." He considered that these two conditions of the weir were not distinguished with sufficient clearness in former discussions on the subject.

The utilisation of scouring power seemed to have been a result attained, in the case of the Severn, to an extent perhaps beyond the anticipations or intentions of the authors of the scheme, but not the less instructive to their successors. He thought that what he had mentioned would show that the question of solid weirs in a river was a most important one, and one which ought to occupy the attention of any engineer who was going

to improve a river bed. The system of solid weirs claimed to do what the systems illustrated in the diagrams did not claim to do, namely, to give a really better discharge for the floods than the unimproved river itself gave. He thought, therefore, Mr. Vernon-Harcourt should either withdraw that portion of his Paper which professed to deal with solid weirs, so that he might not influence the case by treating them in the way he had done, or that he should amplify the portion of his Paper relating to fixed weirs. Mr. Parkes.

The cost of various kinds of movable weirs had been given by Mr. Vernon-Harcourt as from £40 to £70 per lineal foot. He did not know what the actual cost of the Severn weirs was, but they were originally estimated at £7 per lineal foot; and as, to cross the river, three times the length was required, that made them £21 per lineal foot of breadth of the river, or one half the cost of the cheapest weir Mr. Vernon-Harcourt had quoted.

Mr. R. Rawlinson, C.B., had not intended to speak on the question of movable weirs, but there was one point with regard to the action of solid weirs in a river which had not been referred to, and he could very simply state it. Diagrams of one of the weirs on the Severn were given in one of the Rivers Pollution Reports, and the action was this. The river rising in flood, say a mile above the weir, rose a foot; upon the fixed weir it only rose an inch. As the river went on rising beyond the influence of the weir foot by foot it added inch by inch on the weir, so that, when there was a depth of 10 feet in the river, there would be only one of 10 inches on the weir. Now, he held that those who cried out against weirs being such fearful obstructions to a river, could not know what the real action of a fixed weir was. If the river went on rising the weir was lost entirely to view, and the flood flowed on as if the weir did not exist. Rivers with fixed weirs might have relief from by-washes, having movable plank stops in 10 or 12 feet lengths. A foot-bridge placed over the by-wash would enable the stop-planks to be placed or removed by hand as required. By-washes were common on canals, impounding reservoirs, and on some rivers where there were mills. Mr. Rawlinson.

The Rev. Dr. Pearson said, somewhat like M. Girard,[1] whom Mr. Buckley had complimented so highly, he was not a member of the Dr. Pearson.

[1] M. Girard was a civil engineer in private practice; and it was said, in the "Annales des Ponts et Chaussées," that his invention had been adopted by the Administration with the view of encouraging voluntary efforts. He was accidentally shot by a Prussian sentry in February 1871.

Dr. Pearson. profession, but as he had ventured in a scientific society to which he belonged to bring forward this subject, he hoped he might be allowed to make one or two remarks upon it. In bringing it before his own society at Cambridge, he said that the subject had not come before this Institution, and he believed he was right in saying so. He did not wish to make any remark in regard to fixed weirs; and in saying what he had said, he only referred to the movable weirs such as those that are used in France. He thought that there need not necessarily be a contest on the present occasion between fixed and movable weirs, as M. Chanoine, who, he considered, was the most inventive, if not the most successful engineer concerned in these matters, had simply improved upon the system of M. Poirée, which again was only intended to be an improvement on the old system of stanches: such as also existed in England, but which all would allow were now antiquated. He admitted that the system of needles, such as was used on the river Meuse, was also an extremely suitable invention; anyhow, he thought that a weir which was capable of being lowered absolutely into the bed of the stream must cause a smaller obstacle to the discharge of the flood water than a solid weir, although he fully admitted that the results must be tested by what had actually taken place, and not only by theoretical views on the subject. One large river, the Shannon, had not been referred to, but the floods on that river had seriously been complained of. He had been unable to find the Report referred to in Mr. Vernon-Harcourt's Paper by Mr. Forsyth and Mr. Manning, on the subject of that river, but it had occurred to him, from a theoretical point of view, that the self-acting shutters or valves on M. Chanoine's system might possibly relieve the pressure of water considerably, especially as the navigation on the Shannon was not of that primary importance which it was on the Seine, where it had been found necessary to modify their mode of action in practice. He had seen the weir at Port-à-l'Anglais, and had conversed a good deal with the lock-keeper, and he was led to think that the objections to the working were not so great as Mr. Vernon-Harcourt seemed to represent. It must be remembered that M. Chanoine was not now alive to defend his own system. He had nothing more to say, except that he spoke merely as an outsider. He thought it very probable that for the large depths which it was now thought desirable to obtain on the river Seine, a system such as that of M. Chanoine's would not be really practicable, and that it was necessary to introduce some new device, such as the rolling shutters described by Mr. Vernon-Harcourt. There was one very important point affecting the manipulation of the

needle system which had not been referred to, which must not be neglected by those who were inclined to employ it, viz., the great difference in the weight of the needles when dry and wet; the difference would be found stated in the "Annales des Ponts et Chaussées," but he could not give the reference at once. He thanked the meeting for permitting him to address them on the subject. Dr. Pearson.

Sir CHARLES HARTLEY remarked that in addition to the valuable Papers that had been read on the subject of movable and fixed weirs, those who were present on the last occasion had the pleasure of listening to some further very interesting particulars from the lips of the Authors concerning the present type of movable dams in France. In considering the broad question of improving rivers by damming them back at times of low water for purposes of navigation and irrigation, and allowing them to run freely by well-directed channels at times of high water, it was hardly possible to avoid speaking of weirs and dams in the same breath. The Authors of the Papers had, however, dealt almost exclusively with the subject of movable dams. That was, no doubt, due to the fact that the subject was a novel one in the annals of the Institution. He thought it might therefore be well in continuing the discussion to confine it principally to movable dams as distinguished from fixed weirs. He intended to confine his observations to a few remarks on M. Boulé's new movable dam closed by vertical sliding doors and trestles—an arrangement which Mr. Vernon-Harcourt had mentioned in his Paper, but in very few words. Mr Buckley had said that in France rather over 60 per cent. of the movable dams that had been erected were either after the type of the Poirée needle dam, or after what might be called the semi-automatic system of M. Chanoine. Looking at the drawings, it would be seen that the principal feature in the construction of both of those dams was the iron trestles hinged to the apron. In one case they sustained the strain brought on them by the chains of the movable shutters in front, and in the other the trestles themselves directly supported the head of water against the needles from behind. Some years ago, when M. Boulé, Ingénieur des Ponts et Chaussées, was engaged in preparing designs for movable dams for high lifts, he considered that it would be more desirable to improve on the system of Poirée than on that of Chanoine, inasmuch as it appeared to him that the trestle of the Chanoine system and the backstay of the movable shutter seemed to be doing the same thing twice. It was obvious that the trestles must be sufficiently strong in themselves and close Sir C. Hartley.

Sir C. Hartley. enough to each other to hold up the shutters, unaided by their backstays, against any head of water that could be brought against them. On the other hand, M. Boulé considered that the Poirée system was one which should be limited to lifts not exceeding 7 feet, and that the needle should not be longer than could be readily manœuvred by one man. Therefore the height of the frame in such a case would be limited by the length of the needles. These views led M. Boulé to devise a plan for converting the frames at Port-à-l'Anglais (a place which Sir Charles Hartley visited two years ago) into buttresses for the support of ordinary sliding doors, like mill sluices, directly against the frames (which were 15 feet 6 inches high and 3 feet 6 inches apart), thus altogether suppressing the movable shutters with their complicated accessories. This new system of gates was tried at Port à-l'Anglais in 1875, and the pool, which up to that time had been maintained by the Chanoine system, was temporarily held up, through the medium of the gates of the new model, to a height of 12 feet 9 inches above the sill. The draw-doors, which were fitted with angle-irons to keep them in place when being lowered or lifted, were in three tiers or rows, and three oak gates, 3 feet 6 inches wide, 4 feet 3 inches high, and 3 inches thick, were worked vertically against the two adjacent trestles. Thus there were eighty-one gates for the twenty-seven bays of the dam, which had a waterway of 94 feet. To prepare for floods, the gates were lifted with sufficient expedition by means of a travelling crane, which went across the surface bridge from end to end. This crane lifted first the upper row; then, when the waters had fallen, the next row, and occasionally the third row. The gates were at once conveyed, by a wagon running on the same rails as the crane, to stores close at hand. The operation of re-fixing the gates was done by the same simple machinery. The trial was so successful that a ministerial order was given to construct the Port-Villez dam on the same system. Perhaps Mr. Vernon-Harcourt would be able to say whether M. Boulé's system was likely to be permanently used at Port-Villez in connection with the very substantial trestles or iron frames which were there already, and which Mr. Vernon-Harcourt had explained in detail. He also said that there was once an idea of applying needles to that frame, and he explained that the scantling would have to be very great to resist the pressure of the water. Compared with the vertical rolling shutter plan, which it had also been proposed to apply directly against the trestles at Port-Villez, the lifting machinery must evidently be much more powerful than that required for the Boulé sluices; and, besides, as each bay would be opened by a single lift, and not gradually as the level of

the floods subsided, the water would not be spread uniformly over Sir C. Hart
the whole width of the dam as on M. Boulé's system. M. Boulé claimed as the advantages of his plan that his gates were very much closer than the Chanoine shutters, that the cost of construction and maintenance was less, that there was no submerged mechanism, and that the dam could be readily raised much higher, and even to the level of the banks of the river, if desirable; but there might be one disadvantage, namely, the slowness of manœuvring in times of sudden flood. That, however, was an objection which could be removed by having an automatic arrangement in some of the doors, or by perfecting the power for lifting the gates with any required celerity. It was evident that French engineers were still far from unanimous on the question of the best kind of movable dams for high lifts. As he had not visited the sites of the movable dams in Indian weirs described so lucidly by Mr. Buckley, he would not attempt to criticise them, but he would ask to be allowed to describe the regulation dam across the Ganges canal at Myapore, which he inspected six years ago, and which was then being successfully worked on the same principle as the plan brought into use for a short time at Port-à-l'Anglais. At Myapore, where the Ganges canal left a branch of the Ganges, there was a regulation bridge. That bridge had ten openings of 20 feet each between piers of solid masonry. Those piers on the upward end had their cutwaters arranged for slides, or grooves, in which were worked three sets of shutters, immediately in rear of one another. As each shutter rested on its own sill, they worked independently of each other. When the two lower shutters were down, a depth of 6 feet of water was constantly maintained in the canal, and when the third shutter, or a portion of it, was brought into operation, a depth was maintained varying from 6 to 10 feet. The upper shutter merely consisted of planks or sleepers dropped down one on top of the other. The two lower shutters were worked with great ease by native workmen by means of two fixed windlasses to each 20 feet bay. The upper shutter required no machinery to work it. The system seemed to answer admirably, and, as he had said before, was similar to that advocated by M. Boulé. In discussing the various types of movable dams and weirs used in India and France, it should not be forgotten that the physical characteristics of the rivers in those two countries were very dissimilar, and that there was a vast difference in the volume of water discharged. For instance, whilst the Seine at Paris only discharged during high floods 60,000 cubic feet of water per second, the two great tributaries of the Ganges, the Jumna and the

r C. Hartley. Sone, discharged at times of flood as much as 1,000,000 cubic feet per second. Therefore, before deciding definitely on a type of weir or dam to be adopted in a new country, great care should be taken to ascertain whether a system which appeared to be the best for a comparatively small river would be equally advantageous when applied to a large river, and *vice versâ*.

r. Redman. Mr. J. B. REDMAN said an exceptional interest attached to the Papers that had been read, from the fact that there was an avowed necessity for some means of more quickly and expeditiously delivering the flood waters of the Thames. Mr. Vernon-Harcourt's Paper contained an historical review of the various types of movable weirs. The draw-door, or primitive sluice-door of timber which was formerly common on the Thames, and which in succeeding years had been stereotyped in metal, had obviously many drawbacks, and those were intensified by the application of that system to great heads of water. Instead of the head of water becoming a servant and assisting in opening the weirs, it affected a larger area of sluice-gate, which consequently had to be made heavier, involving an additional friction, necessitating a larger amount of expenditure on over-head machinery, and the use of planed brass surfaces to reduce the friction. Types of those gates were constructed half a century ago. There was one on the river Lee, but it had been disused and taken up since the improvements had been carried out. There was another on the river Stour, the "Stonar" sluice, near Sandwich in Kent. Both those were manufactured by Hunter and English. They were of simple form moved by toothed racks, and one man could readily run up the gates. But when this old-fashioned principle was applied to great heads of water, it was certainly most objectionable. There was one type of gate which he was surprised that the Author had ignored altogether in his review, namely, the type of sluice-gates which had been applied for the purposes of weirs, in the low countries more extensively than elsewhere, but of which there had been an example in the Metropolitan area within a very few years. He referred to the vertical balance pivot gates upon a vertical shaft. An example of that type existed, though it was now mudded up, on the tidal portion of the river Lee. Under one of the Acts, certain compensation reservoirs were constructed for storing water at high tide for the benefit of millers. A few years ago he was employed by some of the largest mill interests to look into the question of the water supply, and he examined those gates. They did in fact form a weir, 125 feet in length. There were brick and stone abutments at each end, and two intermediate

piers 5 feet 6 inches of brick and stone, so that there were three spans of 38 feet, with a head of water 7 feet. There were two gates to each of these openings. The platform was flush, the gates upon a vertical shaft revolving upon a plane platform. One half the sill abutted against the upper part of the gate, and one half against the lower part of the gate; and the meeting posts or quoins being in the same relative position, each pair of gates abutted against each other. The gates were turned by a cast-iron toothed quadrant on the top of the gates, and there was a small pinion from the overhead bridge, but the head of water running through the inclined surface of the gates of course did the major part of the work. The same principle had been applied in the Low Countries. One practical objection to those gates was the fact that they traversed upon a level platform, and were more likely to be impeded by passing obstructions. But assuming that the sill projected 12 inches above the platform, and the gate had a lip of 3 inches and 9 inches clearance under ordinary circumstances, that objection would be obviated. In some of these gates the pivot was out of the centre, and as soon as they were unlocked, the head of water, acting on the larger area, opened the gate, and they were in fact automatic. In recent times there had been three simultaneous inquiries with regard to tidal and up-country floods in rivers. Mr. Grant Duff's committee, a committee under Mr. Octavius E. Coope with reference to the floods in the valley of the upper Thames, and another under the presidency of the Duke of Richmond respecting the conservancy of rivers. An esteemed member of the Institution, the engineer of the Thames and Severn canal, Mr. Taunton, gave evidence before two of those committees, and referred directly to the position taken by Mr. Parkes.[1] He thought Mr. Parkes was justified in commenting upon what appeared to be an *ex cathedrâ* setting on one side of the opinion that he had advanced, and in asking that that particular passage of the Paper should be expunged, seeing that it was a mere assertion backed by no argument or proof. Mr. Redman

Mr. F. G. M. Stoney observed that for the last ten or twelve years he had devoted himself almost exclusively to the designing and working out of suitable appliances for controlling water in rivers for the purposes of irrigation and navigation. Mr. Stoney.

Before attempting to describe any of those appliances, he wished to lay before the meeting a short outline of the principles by

[1] *Vide* Report from the Select Committee on Thames Floods Prevention, 27 July, 1877. Minutes of Evidence, p. 204.

Stoney. which he was guided. He started with the principle that the first great requirement of every river was that it should be so deep and straight as to be able to discharge extreme floods without overflowing its banks and flooding the bordering lands. His next principle was, that the drainage capacity of a river could not be improved by putting any work into the river, but by taking something out of it.

Starting on such principles, he arrived at a law that standing obstructions, such as fixed weir mounds, could not increase the capacity of a river for discharging floods; he made this statement with all due deference to the experience of some gentlemen who advocated fixed weirs. It seemed to him incorrect reasoning to infer that because fixed weirs caused a deepening of the river bed in their immediate vicinity (the effect being purely local), they therefore increased the drainage capacity of the river. Such deepening might favourably affect the weir, but it did not prevent the flood waters 1½ mile up-stream from being piled up to gain new head for velocity of approach to the vicinity of the weir. Reference had been made to the case of a certain weir, where, when 1 inch depth of water flowed over the weir, the flood rose 1 foot 1½ mile up-stream, and with 10 inches depth of water flowing over the weir, the floods rose 10 feet at the same place up-stream. This would show that the weir was fairly able to deal with such water as could come to it; but it also seemed clearly to point out that the fixed weir must have robbed the river bed of a considerable amount of its natural fall; it would be interesting to know how many feet less in height the floods would have risen at that place had the weir not existed. He considered fixed weirs at best but a compromise; they were required to retain as much water as possible, but had to be kept low enough to allow the floods to pass over them. He felt convinced that much better control of rivers could be obtained by movable weirs than by fixed ones. If, in a river capable of discharging floods, it was required to retain water in dry seasons for navigation or irrigation, that object could best be gained by such appliance as would, when moved, cause least obstruction on the river bed, and occupy the smallest amount of the transverse sectional area of the river; and because such a structure was movable it might safely be made to full height to retain the full head of water for all purposes. He considered fixed weirs might possibly be used with economy in rivers having naturally an abundant fall, but for such rivers as the Shannon, having very little fall, any fixed obstruction must be directly detrimental.

Mr. Stoney.

About twelve years ago, while engaged on irrigation works in India, he had an opportunity of seeing some rather crude pieces of mechanism in the way of sluices, several of them were ordinary wooden doors under considerable pressure, which had never been opened. He had examined similar doors of smaller size, and had but little doubt that the wooden door pressed against very indifferently finished masonry faces, and got embedded thereon. He had also seen some of the revolving balanced shutters on vertical axes, which mechanical engineers would recognise as of the throttle-valve type; they were about 10 feet high by 6 feet wide. In places the axles had got cut by sand and grit, and it would require great force to move them. He considered sliding friction on a large sluice should be avoided, even though the surfaces could be large to resist cutting up; but to concentrate a heavy load on the necessarily small surface of axle pivots, where they might be cut up by grit, seemed but short-sighted policy. These things, and the necessity for good appliances, directed his attention to the construction of large sluices which could yet be easily actuated under heavy water-pressure by manual power. He had for eight years been familiar with the plans of the various movable weirs adopted by the French engineers, but before acquiring this knowledge he had worked out the principles of his own system of large sluices for rivers; and it happened that he had worked in the opposite direction to the French engineers; while they made everything shut down to the river bed, he made his sluices to be lifted, and leave neither work nor obstruction in the river bed (Plate 6).

He thought the French systems were open to some serious objections, inasmuch as they required a very large proportion of the materials and workmanship to be buried in the river bed, at increased cost of construction and maintenance, while they entailed more or less permanent obstruction in the river, and were troublesome to work, and the moving parts were numerous and liable to fracture and loss. One serious objection struck him as to all but the needle system; so far as he understood, there was but little power of regulating the flow of water by degrees as the floods increased. The first opportunity he had of trying one of his sluices arose soon after he came from India ten years ago. He had an engagement with Messrs. Bell and Miller, of Glasgow; that firm were carrying out some large waterworks in Brazil, and they had designed for the Pelotas works a sluice of 20 feet span and 9 feet deep. The duty of the sluice was to dam up the river, whence the water was drawn off into reservoirs, settling tanks, &c.

. Stoney. The river was subject to heavy floods, which carried down mud and floating débris, and at such times the sluice should be entirely open, and no water allowed to enter the reservoirs. In considering the difficulty of working an ordinary sluice of 20 feet span, with about 20 tons pressure on sliding friction, he saw that, in a country so far away from skilled labour, it would be difficult to apply sufficient power economically, and troublesome to work. He had previously designed sluices in which the pressure should be carried on free rollers instead of sliding friction. He suggested his plan to Messrs. Bell and Miller; they adopted his arrangement, and permitted him to patent it for his own benefit. The principle of this large sluice was extremely simple. Most engineers were familiar with the working of rolling bridges across large spans. The idea occurred to him that sluices might be worked similarly on free rollers if he could only devise a simple means of suspending the rollers so that they would work against a vertical rail, and be free to follow their natural relative motion with the gate rolling on them. He soon found that a simple chain loop, passing round a small pulley suspending a frame with rollers, one end of the chain fixed to the upper end of a rail on the back of the gate, and the other end of the chain attached to a fixed point, such as the upper end of the stationary vertical rail, met all the requirements of the case. The rollers moved half the distance travelled by the gate, and the length of the chain loop always accorded with the position of the rollers, while they were moved by the motion of the gate pressing against them.

In the Pelotas sluice (Plate 6), instead of allowing the gate to slide in the usual way against planed faces on the down-stream side, he made the face on the up-stream side, so that the tendency of the water-pressure would be to separate the gate from the fixed faces, and the entire pressure was carried on free rollers at the back, on the ends of the gate. To facilitate the adjustment the front faces on the ends of the gate were in this case made wedge-shaped, so as to touch fairly water-tight at the same time that the bottom of the gate touched the sill in the floor, which was on a level with the river bed. The gate was lifted by a pair of strong screws, one at each end, simultaneously actuated by simple bevel gear, worked by a pair of pinions on a horizontal shaft having a handle at each end. This sluice, with a clear waterway of 20 feet and a pressure of about 20 tons, was worked by two Spaniards. It could be raised about 10 feet, and had been in continual service for the last seven years without costing anything for repairs, or getting out of order. ... had answered well, and had given every satisfaction to its

proprietors, while the cost, including all fittings and gearing, amounted to only £245. Mr. Stoney.

A few years ago he had made, for a place near Welshpool, four sluices of a like kind; they were 12 feet clear span, and opened 7 feet; one pair might be subject to a pressure due to 14 feet head of water. In these gates the entire front faces were inclined planes. In 1876 four small sluices on free rollers were made, and put into the new Jaoli locks on the Ganges canal, by Mr. Richard Foley of the D. P. W.; they had neither screws nor racks, but were easily actuated by a pair of common close link chains passing over sprocket wheels, carrying a counterweight at one end and the sluice at the other. The wheels were carried on a horizontal axle above, and were turned directly by a simple hand-wheel without any multiplying gearing.

A fair example of such sluices might be seen in those proposed for the under-sluices of the Okhla weir in the same irrigation works. These sluices had an area of about 65 square feet, and worked under a pressure of about 16 feet head of water. They were compound doors, and were so arranged that the water-pressure made the inner door tight just as in a common sluice, but that door was relieved of pressure before the sluice was opened.

To accomplish this there was as at first a sluice door on free rollers; on the down-stream face of this door was a recess, into which the back of another door neatly fitted; when both doors, always moving together, were shut down, water leaked in between them, put all the pressure on the inner door, and pressed it home against the sluice frame, while it relieved the original door and rollers of all pressure. In the bottom of the inner door was a sliding valve of such size as to be easily worked, and capable of letting the water out from between the doors faster than the leakage let it in. The first operation in opening the sluice was to open this valve, when the inner door was quickly relieved of pressure, which was then transferred to the original door, and on to the rollers, when the sluice was ready to be lifted as before. This kind of compound sluice was very suitable for canal locks and graving docks, &c., when hydraulic power was not at hand. Mr. Buckley had referred to the Okhla weir, and Mr. Stoney wished to say he had, after some correspondence with Mr. Clinton Anderson and Mr. J. C. Beresford, sent out plans and proposals for sixteen of these double-door sluices in addition, to form a cap for the Okhla weir. The weir cap was intended to be 2,500 feet long, composed of sluices on rollers, in eighty spans of

Mr. Stoney. 31 feet 3 inches from centre to centre of the iron piers, which were but 9 inches thick, leaving clear spans of 30 feet 6 inches. The gates when shut would add 3 feet to the depth of water on the crest of the weir, and were designed to be lifted 10 feet. The cost of all the ironwork and fittings was estimated at under £6 per lineal foot, and the cost of the sixteen compound under-sluices was estimated at £220 each; single-door sluices would be cheaper.

He wished now to call attention to a more recent design for some large sluices for a special case. The clear span was 40 feet, and the depth of water 12 feet. The gates were designed to be lifted 12 feet. In this case the up-stream face was vertical, and the gate simply fitted at its ends against planed guides in the pier faces, the contact being kept close by self-adjusting slips, and the gate was free to press down fairly on a level sill. He considered this much better, more easily made, and cheaper than the wedge system. The gate was simple; it was composed of two main girders, placed equally at each side of the centre of pressure; cross vertical beams connected these girders, and carried the sheeting and top of the gate. For the information of those who wished it, he would mention that the static water-pressure was 81 tons. Each girder was calculated to carry 60 tons, with a strain of 4 tons on the net section of the iron, making a total strength of 120 tons, with a factor of safety of 5 to carry 81 tons. The weight of the gate was 18½ tons, and the moving weight, including rollers, was roughly 20 tons. The whole was arranged to be lifted by a pair of strong right and left screws (like a railway carriage coupling), pulling out of each other so as to eliminate all friction of fixed collars. These screws were placed horizontally on a foot-bridge, and acted on large nuts travelling in guides; each nut pulled chains which passed over large pulleys down to the gate, where they were symmetrically grouped round its centre of gravity. At the foot of the gate some displacement was arranged to produce an initial upward force of about 5 tons, so that the maximum work to be done was at the top of the lift—a point to which the gate might seldom have to be lifted; and at the lower portions of the lift, which would be in more frequent action, the work to be done would be least, the contrary being the case to an inconvenient degree in all sliding sluices. Mr. Vernon-Harcourt had given the cost of some of the French systems as reaching £140 per lineal foot. This seemed extreme, but much material and workmanship so very indirectly applied in those cases no doubt augmented the cost greatly in proportion to the effective weir. He had full confidence that his system of large

span sluices in a single moving part, that could be actuated at all times to any required degree, would compare favourably as to cost with any system at present in use. Mr. Stoney.

Engineers might, from the figures above given, judge of the strength provided for in the foregoing 40-feet span sluice, and with the following figures might form a fair notion of the comparative cost. The weight of this large sluice-gate, with the rollers, &c., moving with it, was 19 tons; the fixed castings, such as roller rails and guide beams, 3 tons; foot-bridge and lifting gear, 5 tons; in all 27 tons. Putting this even at £30 per ton would only amount to £20 per lineal foot—not much considering that the depth of water was 12 feet. In addition to this, piers and floors had of course to be provided.

It might be objected that this system of large lifting sluices could not be applied to the navigable channel of a river, but he had much pleasure in stating that it could easily be so arranged as to allow ships to pass through between the piers, the spans being made large enough, and this with a small increased cost as compared with the same spans in the ordinary application of his system.

Professor W. C. Unwin said he became acquainted some two or three years ago with the sluice, a model of which Mr. Stoney had exhibited on the table. Certainly it was one of the most ingenious he had ever seen, and it worked in a most admirable manner. He did not think anything better could be adopted in cases where a large pressure of water had to be resisted. Mr. Vernon-Harcourt's Paper had given him very great pleasure, although he had become acquainted with the weirs there described from reading the rather copious French literature on the subject. Four years ago, Mr. Fouracres, when in England, was good enough to talk with him about the weirs in India, which no doubt were suggested by the French weirs. As Mr. Vernon-Harcourt seemed to have found hardly any English reference to those French weirs, he wished to mention that they were pretty fully described in some Papers in the "Engineer", ten or twelve years ago. It was only fair that that should be mentioned, as he believed it was the first adequate reference in English to the subject. He had not much additional information to give about those weirs, because Mr. Vernon-Harcourt had visited them, and had consulted all the sources of information upon them; but in regard to the size to which they could be extended, it might be useful to mention that in Heusinger von Waldegg there was a reference to a needle weir in Prof. Unwin.

Prof. Unwin. Norway, almost identical in size with the Port-Villez weir. The reference was only a short one, but he alluded to it because apparently, in that case, a needle weir was adopted nearly as large as that at Port-Villez. At the last meeting it was stated that at the Desfontaines drum weir, shown in the diagram, it had been noticed that some of the paddles stood up, others lay down, and others were inclined, and the reason of this had not been discovered. He might possibly throw a little light upon that peculiar action. It appeared that when Desfontaines first designed that weir he was very much afraid of the action which would occur if, on opening the sluices at the end, the whole of the paddles suddenly went down. A great flood of water would then be liberated over the weir, and he contrived very much to avoid the simultaneous opening of all those paddles. In his first designs he employed behind the free or upright paddle an inclined strut very much like that in the Chanoine weir, which slid in a groove, and he had across the whole length of the weir certain angle-irons or locking bars, which could be pushed out before the sluice was opened, so that as the strut came up against the bar it was stopped. Those locking bars were so arranged that any number of paddles could be liberated to one-half of their extent or more, as was required. In that way the paddles could be gradually opened, and the sudden release of the water, by opening them all at once, was prevented. It was accidentally discovered that nearly the same result could be achieved in a much more simple way. In the Desfontaines weir, sluices had been contrived at both ends. When the sluices went one way they admitted the head of water to the upper side of the lower paddle, and *vice versâ*. It was found that having two sets of sluices, one at each end of the weir, if they worked those two sets in opposite ways they obtained the peculiar effect of some paddles standing up and some lying down. If they worked the sluice at one end of the weir so that the paddles ought to go down, and worked the sluice at the other end so that the paddles ought to go up, and had the sluices not exactly equally open, then some paddles would be standing up and some lying down. He believed that that was the origin of the action referred to. At the last meeting Mr. Parkes raised a kind of small flame in the embers of what seemed to have been at one time a rather burning controversy. He especially raised the question whether experience was not a great deal better than theory in reference to questions of this sort. He would be a very bold man indeed who would question Mr. Parkes' facts, or would think that any hydraulic theory was

perfect enough to enable him to upset them. He, therefore, had no idea of rebutting the facts or conclusions, but he wished to understand exactly what were the questions raised in regard to these fixed weirs. When he turned back to the original Papers, as Mr. Parkes had recommended, he did not find in them very much with which he could find fault. Mr. Cubitt alleged that if there was a river of very varying slope, some parts of it torrential, and some nearly stagnant, weirs should be built in that river in such a way that the land floods would be less deleterious than before. He saw no reason to quarrel with that statement; but with regard to practical experience on the Severn, he just wished to make one remark. According to Mr. Cubitt's statement there were originally on the Severn fourteen natural weirs or shoals, over which there was only 18 inches of water; that those shoals were removed, and in their places four masonry weirs were built. Now under those circumstances, he saw no difficulty in believing that the floods on the Severn might be considerably diminished. It appeared to him that no theoretical question arose in that case, but he found that this experience on the Severn was now being quoted in a way which seemed to him to make it almost a paradox. It was sometimes urged in such a manner that it would be imagined any number of weirs could be built across a river, and the floods would go down more easily than before. That was carrying a perfectly sound and practical doctrine to an extreme conclusion. Mr. Parkes raised three separate questions. The first was as to the action of oblique weirs, the second whether when a weir was built across a river the bed of the river above the weir was or was not deepened by the action of the weir, and the third question was whether or not the discharging capacity of the river was increased by weirs. With regard to the question of oblique weirs, he would like to say, that, in his opinion, there was no doubt that in such cases a greater discharge was obtained than from a normal weir; but the question was, whether that advantage was a large or small one. No doubt if the river was flowing with a very small velocity, the oblique weir acted almost like a normal weir of extra length; but as in flood the river was flowing with great velocity, it seemed to him that the advantage of the oblique weir was at once diminished. In the latest French treatise on navigation, M. de Lagrené stated that there were no sound experimental results which gave any information about oblique weirs. Why he was inclined to doubt the efficacy of the oblique weir was, that observations showed that the particles of water going over the oblique weir followed directions which, to the eye, were apparently parallel Prof. Unwin.

Prof. Unwin. to the axis of the stream, and then it was very difficult to see how the advantage of the oblique weir could be great. In any kind of orifice the discharging area must be measured normally to the direction of flow. He had referred to the Papers in the Transactions of the Institution with regard to the oblique weirs, and he would wish to refer to one point about the Severn weirs. In the theoretical discussion of the question, Mr. Cubitt said, that if a river was widened out to three times its original width at the weir there would be much less backwater. He also said that all the advantage of that widening of the river might equally be obtained by putting a weir obliquely in the straight course of the river; but when he came to examine the drawings of the Severn weirs he did not find that that was at all the kind of weir actually adopted, especially in the case at Tewkesbury. The stream was widened very much, and the obliquity of the weir to the axis of the widened stream was much less than 3 to 1. The river had been so widened where the weir was, that nearly all the advantage of extra length in the weir was due to the widening and not to the obliquity of the weir. No doubt that widening of the river tended very much to diminish the backwater produced by the weir. With regard to that curious fact which Mr. Parkes mentioned of an old barge being lifted up and placed on the crest of the weir during flood, there was a great deal of other data of the same kind available. In some cases it appeared that a wedge-shaped bank was formed by silting which came almost up to the crest of the weir, but in many other cases there had been considerable deepening of the bed of the river above the weir. In the old treatise of Minard several instances were quoted, where gravel was thrown in above the weir, and was scoured out at the first flood. He was therefore inclined to agree with Mr. Parkes that there might be some deepening of the river above the weir. The other question as to whether not only an equal but a freer discharge of floods could be secured in a river impounded than in a river not impounded, was too complicated for him to enter upon at that time, but it seemed to him that it depended upon the fall of the river which was available.

Mr. Bruce Bell. Mr. Bruce Bell, said that as his colleague, Mr. Miller, and himself were the engineers of the works in Brazil alluded to by Mr. Stoney, he wished to make a few remarks in regard to the weir referred to. The river mentioned by Mr. Stoney was selected as the source from which to supply the town of Pelotas, in Rio Grande do Sul (Brazil), with water by gravitation. And as any fixed weir, erected at the point chosen for the source of supply, would have

subjected the country during the rainy season to severe floods, which no doors or sluices could have possibly prevented, Messrs. Bell and Miller decided to abandon all idea of a fixed weir, and to form a chamber of masonry in the river, and construct within it a movable vertical gate or weir, filling the entire space, which in time of floods could be lifted entirely out of the water, and thus leave the floods full scope to descend. The point chosen for this work was a gorge in the river having a good rocky bed suitable for foundation. The interior width of the chamber was 20 feet, the height of the door 9 feet 6 inches, the floods rising at times to 12 feet, presenting a solid body of 240 square feet of area. Mr. Bruce Bell.

They found, however, that the machinery necessary to overcome the friction upon an ordinary sluice face of such a body of water, would be too cumbrous and slow for two men to work. Mr. Stoney suggested the idea of reversing the face of the door, and making it face against the direction of the stream, and obtain the pressure necessary to keep the dam watertight by making the groove in which the door had to slide wedge-shaped, so that when shoved down to its position, it would be forced by the inclination against the face of the wedge-shaped groove, and so make it perfectly water-tight. The pressure of the weir under the action of the stream, in place of bearing against a flat surface, was conveyed to the bearing surface of the groove in the chamber facing the stream by rollers upon the back of the gate, which materially lessened the friction. This arrangement was shown in the plan prepared by Mr. Stoney from their working drawings.

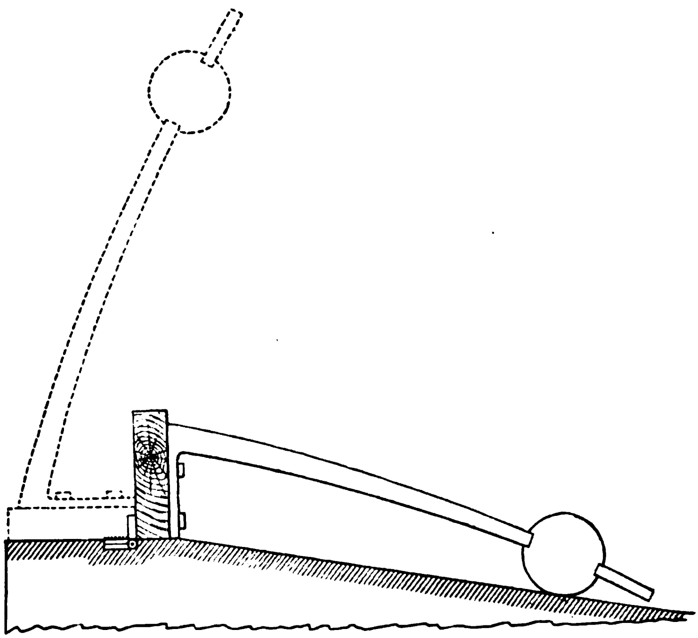
The work was carried out under this arrangement, and proved a complete success; and as Mr. Stoney had stated, the weir was acting now as well as when first erected, and it could be raised at full flood by two men by the action of a simple wheel and pinion. It is a question whether a gate of such a size had ever been erected which needed so little power to lift it. He considered that Mr. Stoney was a very ingenious man, and his designs were well worthy of the consideration of dock and hydraulic engineers, particularly his arrangements for sluices for docks and locks. Mr. Bruce Bell some years ago advised Mr. Sandeman, who was at that time engineer for the Weaver navigation, to adopt them upon the large locks he was erecting upon that river, and there were now no less than twenty-eight sluices at work, which had been very successful in action.

Mr. Baldwin Latham said he would describe a very simple self-acting weir on the River Weaver, at Nantwich. The apparatus Mr. Baldwin Latham.

Mr. Baldwin Latham.

consisted of a movable plank, hinged at the bottom, and fixed on the crest of a stone weir (Fig. 2). The plank was 18 inches in

FIG. 2.

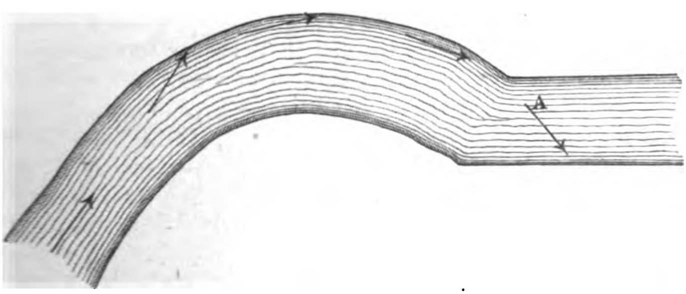


depth, and the weir was 29 feet in width. On the up-stream side of the weir, four curved iron levers were fixed to the plank, each lever being 5 feet 6 inches long, and on the levers iron weights were placed, the weights and length of lever being so adjusted as to keep the plank in a vertical position under a given head of water. When, however, this head of water was exceeded, the extra pressure caused the plank to tip over, and with the first movement, the leverage of the counterbalance was shortened. The result was that the dam suddenly fell down, bringing the levers into a nearly vertical position, as shown by the dotted lines in Fig. 2. The weights on the levers still overhung the hinge of the plank, so that when the water had flowed off to such an extent that the pressure was removed from the plank, and the weight on the levers could overcome the resistance, the plank again assumed the vertical position. The action was accelerated by reason that, in moving back the leverage the counterbalance increased, so that when once started the plank quickly took the vertical posi-

Mr. Baldwin Latham.

tion. He was unaware who was the inventor of this ingenious device, but he had been informed that it had been in operation for more than fifty years. As he had given some attention to the movements of water in rivers, he would endeavour to demonstrate why in some cases a fixed weir on a river led to a scour immediately above the weir, and not to a silting up, as was at one time supposed must be the consequence of the erection of such an obstruction in the channel of a river. Hitherto, with few exceptions, works on hydraulics treated only on the movement of water in the horizontal plane of a river; but D'Aubisson showed in his treatise on "Hydraulics" that water moved both round the horizontal bends and over the curved bottom of a river by a series of reflexions. Three years ago Professor James Thomson, of Glasgow, endeavoured to demonstrate that the movement of water round the bend in the horizontal plane of a river generated centrifugal force. But the force at work in a river was one that caused the bend, and was therefore anterior to the generation of centrifugal force, which Mr. Latham did not believe had anything to do with the direction of the currents in the bend of a river. For example, Fig. 3 represented a horizontal bend in a river. On

Fig. 3.



examination it would be found that, as the water moved round the curve, the concave bank was eroded by its action, while a silting up took place on the convex side. It must not be forgotten that the most rapid moving vein of water in a river had some elevation above the veins of water moving with less velocity. So, in a straight channel of uniform section, the surface of the water was convex, highest in the centre where there was the greatest velocity of flow, and lowest at the sides, where there was the least velocity of flow. In a curve of a river, the greatest velocity of flow was on the outer or concave bank; there the surface of the water was the highest, the point of maximum velocity having been

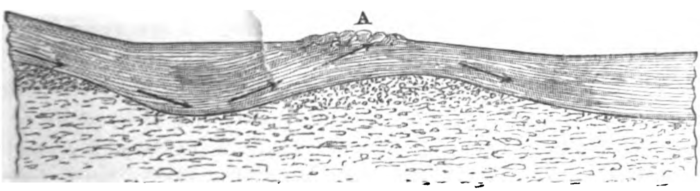
Mr. Baldwin Latham.

shifted from the centre of the stream to the concave bank; as a consequence, on the opposite or convex bank, the surface was abnormally lowered, so that by gravity, movements of water were set up from the raised water on the concave bank towards the low water on the convex bank, and so silt was deposited on the convex side of the stream. The movement of water in the bend of a river was simply due to what might be called the lineal movement of water, or the tendency of water always to move in straight lines, and its subsequent reflexion round the bend. By reference to an experiment with a channel like Fig. 3, it would be found that the movement of the water followed the direction indicated by the arrows. After the water had run round the concave bank of the stream, it would not have a tendency to flow off along the outer bank at A, which should be the case if centrifugal force was in operation, but the current of water crossed over to the opposite side of the stream, and there tended to form a similar curve to the one it had previously left. In the vertical plane of a natural river, it would always be found that the river consisted of a series of deep and shallow places following one another in pretty regular succession, and what were known as holes in rivers always remained as such. The existence of these holes was a sort of standing protest against some of the ordinarily received notions on hydraulics, in which it was held that scour in a river or channel depended upon velocity, and that velocity was inversely as the section, so that with a given volume of water, a large section gave a small velocity of water and little scour, and a small section a large velocity and great scour; consequently, if this doctrine were complete in itself, and the results were only considered in reference to velocity, all these holes or deep places in a river, where the velocity was the smallest, should silt up, and the shallows should be scoured out; but as a matter of fact the reverse was the case. The cause of this anomaly was to be attributed to the varying angles at which water moved in the vertical plane of a river. Where there was a shallow, the fall or inclination of the surface of the stream was the greatest; when the water was deep the fall was the least. A rapid inclination preceding a comparatively flat fall caused the water to move downwards in the direction of the arrows in Fig. 4 and to strike the bottom, by which it was again reflected upwards towards the surface, and might be seen in the lower side of these holes to be gushing up just as if there were a spring at the bottom of the river. This welling up of the water often caused an eddy, as the atmosphere was unable to sustain the column of water thrown up, and consequently it flowed off in all

Mr. Baldwin Latham.

directions, and partly towards the head. The general flow of water down the stream, and the partial flow up the stream, gave a rotating movement to the water, causing the eddy so often observed in these holes in a river. That the currents in a river moved in the way described he had observed when a boy fishing; for, when fishing with a vertical float, having little power of flotation, if the line were dropped into the upper end of one of these holes, the tendency of the stream was to draw the line and float under the water; but when the line was dropped in the lower side of the holes, the upward current carried the line upward, and the float lay on the surface of the water. Venturi observed that the movements of water in the vertical plane of a river were affected by the bed of the stream, and he showed that, in a section such as that illustrated in Fig. 4 the water would flow to the surface at the point A. These movements of water were all due to its tendency to travel in straight lines. The movements of water in the vertical plane of a river acted in a similar manner to those in the

FIG. 4.



horizontal plane, and the concave bed was always eroded, and a deposit occurred on the convex part of the bed of the stream. Applying the observation already made to the case of a fixed weir in a river, such as those in the River Severn, it will be observed that at the points where all these weirs had been placed, the channel of the river was either naturally wider or had been widened; so that, compared with the channel a short distance higher up, the section immediately in front of the weir was greater than higher up the river; in fact, a condition of things similar to those referred to in the case of the deep part of a river had been artificially produced, and the water under ordinary circumstances was deflected towards the bottom of the stream immediately in front of the dam, and was reflected upwards by the dam, which, as would have been observed, was a movement favourable to the removal of deposit. The effect of the great elevation of water by a weir tended to intensify this action of moving water, so that below a weir a deep hole was generally made by the down-

Mr. Baldwin Latham. ward movement of the water, which in its turn was followed by a shoal created by the uprising of the water, just in the same way that the deeps and shallows were produced in a natural river. The obliquity of the weirs in the River Severn also favoured the clearance above the weir, as the water had a tendency to flow in lines parallel to the weir. Fixed weirs might be used in some rivers without detriment, provided the banks of the stream were high, and the water was impounded at a level well below the surface of the adjacent land. In flat districts liable to floods, a fixed weir might raise the height of the floods, and in such cases movable weirs had a decided advantage over a fixed weir; and it was to be hoped that they would be brought into general use in this country, as in many places they could be adopted with advantage.

Mr. Longridge. Mr. J. A. Longridge said he joined in the regret which Mr. Parkes and another speaker had expressed, that the question of fixed weirs had not formed a greater portion of the discussion. He thought it was unfortunate that so much time had been spent upon things which, however interesting they were in themselves, yet from a professional point of view were not of equal importance to fixed weirs. He remembered the discussion which took place a great many years ago; and he had refreshed his memory by referring to Vol. V. of the "Minutes of Proceedings." Sir William Cubitt then seemed to think, that provided the length of the weir was three times the breadth of the river, and the area of section along the line of the weir was equal to the cross section of the area of the river, there would be no obstruction. He laid down that as a general proposition, but in those terms it was not true, though there were circumstances in which it became true. A good deal of vagueness in the discussion arose from the fact that no distinction was made between an overfall weir and a submerged weir. It was, he considered, incontrovertible that in overfall weirs there must be a backing up of water behind.

Take the case of a channel with a uniform slope running with a uniform depth of water. The water in any given length of that channel, say a mile, had a certain amount of *vis viva*. If now a weir were interposed, so as to make an overfall, there must be a loss of *vis viva*; and if at the lower end of the channel it was to deliver the same volume of water as at the top, it must, running the same depth and the same velocity, have the same *vis viva*. The loss, therefore, at the overfall must be compensated by an increase of head above the weir, so that the flood-level must be raised. This must apply to all overfall weirs, whether normal or oblique

to the current. The case, however, was different with submerged weirs. It was quite possible to erect such weirs without any disturbance of the flood-level. This might be shown as follows:— For the sake of simplicity, take the case of a rectangular channel whose breadth was b, depth of water d, inclination I, and velocity of flow v. Mr. Longridge.

The discharge was $v\,b\,d$,

$$\text{or } D = C\sqrt{\frac{b\,d}{b+2\,d}\,I}\;b\,d,$$

$$\text{or } D = v\,b\,d \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

If this channel was crossed by a weir, of which the upper crest was at a distance δ from the bottom of the channel,

l the length of the weir,
Δ the height of the upper pound above the crest,
d_1 = difference of level between upper and lower pounds,
d_2 = depth of weir below lower pound,
h = height due to velocity of approach v,

the discharge from the weir would be—

$$C_1\,l\sqrt{2g}\,\{d_2\sqrt{d_1+h}+\tfrac{2}{3}(d_1+h)^{\frac{3}{2}}-h^{\frac{3}{2}}\},$$

which, when $d_1 = o$, and $d_2 = \Delta$, becomes—

$$C_1\,l\sqrt{2\,g\,h}\left\{\Delta-\frac{h}{3}\right\};$$

but $\sqrt{2\,g\,h} = v$; therefore

$$\text{discharge} = C_1\,l\,v\left\{\Delta-\frac{h}{3}\right\} \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

and equating (1) and (2), and writing $d - \delta$ for Δ,

$$l = \frac{b\,d}{C_1\left\{d-\delta-\frac{h}{3}\right\}}, \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

and since $h = \dfrac{v^2}{2\,g}$,

$$\frac{h}{3} = \frac{C^2\,b\,d\,I}{6\,g\,(b+2\,d)}, \text{ and substituting this in (3)}$$

$$l = \frac{b\,d}{C_1\left\{d-\delta-\dfrac{C^2.\,b\,.\,d\,.\,I}{6\,g\,(b+2\,d)}\right\}},$$

Mr. Longridge. from which it was evident that l varied when d varied, the other elements remaining constant.

The length of the weir therefore depended upon the height of the flood, and it would be seen that a weir which would pass a high flood without disturbance of surface level, would produce an overfall, and consequently a backing up of the head water in a lower flood. For instance, in the case of a rectangular channel of the following dimensions: breadth, 100 feet; inclination, 1 in 3,000; weir 6 feet above bed of channel. The following Table gave the necessary length of weir and sectional area along its crest for these floods, viz., 12 feet, 16 feet, and 22 feet respectively:—

Height of Flood.	Depth on Weir.	Length of Weir required.	Sectional Area of Water in Channel.	Sectional Area of Water along Line of Weir.
Feet.	Feet.	Feet.	Square feet.	Square feet.
12	6	225	1,200	1,350
16	10	201	1,600	2,010
22	16	172	2,200	2,752

It appeared, therefore, 1st. That the necessary length of weir decreased as the length of flood increased, and, 2nd. That the sectional area along the line of the weir must always exceed that of the river channel, and not simply be equal to it, as was supposed by Sir William Cubitt. It mattered not whether the weir was placed normally or obliquely to the stream, provided it had the requisite length. In the former case the river would have to be widened out, and thus would have the disadvantage of decreasing the velocity of approach, and consequently would tend to silt up the channel at the back of the weir and decrease the discharge. On the other hand, the diagonal weir had the disadvantage of tending to scour behind the back of the weir, and to cause an erosion of the bank below the weir, near the up-stream extremity, where the bank would consequently, if of soft material, require some protection. As regarded the increase of depth which had been stated to have taken place in the Severn since the weirs were built, he thought that could easily be accounted for by the fact that previous to the erection of the five weirs, that portion of the river was crossed by no less than fourteen natural dams of sandstone, marl, or gravel, dividing the river into a series of deep pools, separated by a series of rapids, with a minimum depth, in the low-water season, of 18 inches. The removal of these fourteen dams, which took place when the weirs

were built, no doubt considerably increased the mean hydraulic depth of the river, and consequently its scouring power; but such improvement was rather in spite of than in consequence of the creation of the weirs. Mr. Longridge.

Mr. G. Higgin remarked that one point of great interest, as regarded the construction of fixed weirs, was, as to the best form or profile, with a view to give the greatest facility of discharge, and to prevent erosive action on the bed of the river below the weir. It was well known how troublesome and vexatious was the labour entailed by the proper protection of the apron or tail of the weir. The action produced at this portion of the weir was due almost directly to the form or profile of the down-stream side of it. Hence the great importance of deciding on the proper form that should be given to the slope. Mr. Higgin.

In many of the Indian weirs or "anicuts," such, for instance, as the Kistnah, the crest of the weir was horizontal for a distance of 19 or 20 feet, and the down slope was concave, with the intention doubtless of delivering the water at the point where it finally left the stonework in lines parallel to the river-bed. It would be desirable to know how far these results had been obtained. Other Indian weirs, such as the Coleroon, had a vertical drop. In Spain there were many examples of old weirs, some of them six hundred or eight hundred years old, the generality of which had their down-stream side made in a series of gentle slopes, almost indeed horizontal, broken by small steps. The result of this might be seen in such weirs as those of the rivers Turia and Jucar. In these weirs it had been necessary to protect the river-bed for a considerable distance below the tail by heavy paving held in place by a system of piling with horizontal walings. This protection piling extended in some places 200 feet beyond the termination of the weir proper; but a deep hole was always found at the termination of the paving, and there was a continual tendency to an enlargement of this, and erosion of the bed backwards, which was only prevented by constant care and attention. In some few instances in Spain the weirs were made with a vertical drop, notably in all the small mountainous rivers of the north, and in other places, such as in Alicante, where there was a weir with a vertical drop of about 24 feet. Perhaps the most extraordinary instance of a vertical drop was that of the dam across the River Lozoya, for supplying Madrid with water. This dam was 105 feet in height, and during floods the river poured over it in an unbroken sheet. The dam was built of ashlar founded on rock.

About sixteen years ago he had occasion to construct a large

Mr. Higgin. weir across a river in Spain, for an irrigation canal, of which Mr. Bateman, Past President, and he were the engineers. This weir was founded on a soft rock; the crest was 20 feet above low water of the river, and the profile of the weir was of the ogee form; the tail of the weir was benched into the rock. In spite of this, the floods exerted an erosive action on the bed, a large hole having been scooped out of the rock at the tail, where the apron ended.

The fall on the line of this canal was about 6 feet to the mile; it became necessary therefore to introduce a number of falls. The first of these, which had a total drop of about 17 feet, was made with a ramp or paved slope of 1½ to 1. The disturbance created in the lower part of the canal below the fall was very great, and was propagated for a long distance, destroying the banks of the canal. In the remainder of the falls, therefore, the form of construction was varied, and they were built in steps, each step being 6½ feet wide and 3¼ feet high. The water fell into a pool 13 feet long, and 3¼ feet deeper than the bed of the canal. This system answered perfectly; the water leaped down from step to step, and fell entirely deadened into the pool, from whence it flowed away with a gentle easy current. One of these falls was 40 feet deep, and the descending water was a beautiful sight.

The system of vertical drops, where practicable, would seem, therefore, to be the best for destroying the erosive action of the water; and this was in accordance with what might have been expected from the laws which governed the fall of water and other bodies.

As regarded the silting up behind the weir, he understood Mr. Parkes to say, that in the Severn the effect of the weirs had been to deepen the bed of the river above them. This was, he believed, opposed to the general experience of engineers. In the Indian rivers the silting up of the river-bed appeared to be the invariable result of the construction of a weir. Colonel Baird Smith in his work on the "Madras Irrigation Canals," gave it as his opinion that such an effect must be accepted as a natural consequence of a weir. In the weir above referred to, in Spain, although the crest of the weir was 20 feet above low-water level, the first winter's floods, after the closing in of the breach, sufficed to fill the whole bed of the river up to the level of the crest; and so it had remained to this day. In fact it would appear to be the tendency of all weirs placed across rivers subject to heavy floods, and carrying consequently large amounts of detritus, to elevate the river-bed. When closely examined, it would be seen that such an effect was merely

a natural consequence of the laws that governed the flow of water in open channels. Mr. Higgin.

The oblique position of the weir appeared to be entirely a question of circumstances. In cases where a river-bed had a considerable fall, and the weir was consequently never likely to be submerged, and where the banks were sufficiently high, there could be no objection to placing the weir at right angles to the course of the stream. Where the banks were low, and the natural fall of the river-bed small, so that in times of flood the weir might be submerged, obliquity should be given to the weir. There was no mystery about the oblique position; the effect of thus placing the weir was merely that of increasing its discharging capacity; so that, other things being equal, an oblique weir did increase the discharge on account of the extra length thus obtained. A simple calculation would explain this. Take the case of a river 100 feet wide and 10 feet deep, flowing with a mean velocity of 2 feet per second; the discharge would be 2,000 cubic feet per second. Now, if the fall below the weir was sufficiently great to prevent the backwater from rising to the level of the crest, and the banks were high, the weir might be placed directly across the stream. With the ordinary form of weir, a depth of 4 feet on the crest would discharge the whole 2,000 cubic feet in a second; if, however, the banks were low, and it was desired to keep down the height of the water, the weir must be placed obliquely. If it was placed so obliquely as to double the length, the depth need then, roughly speaking, only be 2 feet on the crest to discharge the same 2,000 cubic feet of water per second. This was not exactly correct, because the best experiments showed that an oblique weir discharged per foot of length rather a less quantity than one placed directly across the stream. The old Moors and Spaniards well understood this; in cases where the fall was great and the banks high, their weirs were generally placed directly across the river; in opposite cases the weirs were placed more or less obliquely. The question as to the desirability of oblique weirs appeared, therefore, to be entirely one of circumstances. There was one other point of great interest as regarded weirs, and that was the laws governing their discharge. About this most important point there appeared to be great want of information. The various experiments that had been made—the Lowell experiments, those of Castel, Mr. Blackwell, M. Bazin, and others—were all conducted on weirs of a short length, seldom exceeding 10 feet, and under exceptional conditions as regarded the form of the weir, and the materials of which it was composed. The results obtained were more suitable for gauge

Mr. Higgin. boards than for large weirs. These latter were ordinarily composed of ashlar or of rough paving. The form or profile rarely approximated to the form of the gauge boards used in the various experiments, and there was reason to believe that the coefficients obtained were not applicable to the cases of large weirs. It was only comparatively of late years that the experiments of Messrs. Darcy and Bazin had shown how all-important was the question of the materials of which the sides of channels were made. These experiments had revolutionised the old formulæ for the discharge of water in open channels; the same laws applied to the discharge over weirs, and no doubt the material of which the crest was composed had a large influence over the discharge. In the case of the Henares weir, he found that with low depths of water on the crest, the calculated discharge, using the ordinary coefficient, was much larger than the actual discharge. For a form of crest, such as that of the Henares weir, a coefficient of 0·40 was given in most treatises on the subject; but in practice, with depths of only a few inches on the crest, the coefficient was not more than 0·28 in the formula $v = c\sqrt{2gh}$. The effect of this laxity of the formula might, he thought, be seen in some of the calculations made of the discharge of rivers; for instance, Mr. Law, M. Inst. C.E., in his evidence given recently before the Thames Enquiry Commission, stated the mean daily flow of the Thames at Teddington weir to be more than 133,000,000 cubic feet. Mr. Leach, who made a long series of measurements at the same weir, estimated it at 50,000,000 cubic feet. Mr. Haywood estimated it at from 70,000,000 to 90,000,000 cubic feet. This great divergence of opinion pointed, in his opinion, to a great difference in the various coefficients used, as it was not likely that the mean daily flow of the same river at the same point could vary so much as from 50,000,000 to 133,000,000 cubic feet in the course of a few years.

It was much to be desired that some better rules could be fixed for calculating river discharges. The subject was one of vital importance for all riparian proprietors, who, like the dwellers in the Thames valley, had to suffer from the periodical inundations of their property. With the existing knowledge of the rainfall, and of the quantities that might reasonably be expected to flow off the ground, there was no reason why the dwellers in the Thames valley should not be secured from inundations.

In the case of such a river as the Thames, where, in most cases, the banks were low, it would probably be necessary to adapt, to many of the weirs, a self-acting movable crest, such as that which

it was intended to apply to the Sone weir; but whether this were necessary or not, it was within the bounds of engineering science to arrange the Thames weirs in such a manner as to prevent the excessive flooding to which the valley was now subjected, without interfering with the navigation. Mr. Higgin.

Mr. G. J. Symons thought it was a misfortune that the title of the Paper was "Fixed and Movable Weirs." It would have been better to have simply taken movable weirs, and treated of fixed weirs at another time. A statement in the *Hereford Times* of last week curiously illustrated what Mr. Parkes said about the Severn weirs. That paper contained an account of a meeting in which the Earl of Coventry and others took part, with a view to memorialise the Severn Commissioners, because of the floods that existed at present, and which were attributed to the weirs on that river. With respect to the bibliography at the commencement of Mr. Vernon-Harcourt's Paper, that gentleman had, unfortunately, overlooked a very interesting paper which had been read by Mr. J. Neville, "On fixed and movable weirs," before the British Association at Dublin in 1878. That paper had been reprinted by Mr. Edward Easton in the form of a pamphlet, and he would strongly recommend it to the consideration of all the members of the Institution. At the end of Mr. Vernon-Harcourt's Paper, there was a reference to the application of these movable weirs to the Shannon. He considered it a great pity that the advisers of the Irish Board of Works seemed to have adopted the foregone conclusion that the French movable weirs, for which he himself had a great respect, were of no use. He was glad to notice that in the discussion which took place at the Dublin meeting, and which also had been printed, Mr. Price, who was formerly engineer to one of the principal Irish railways, expressed the following strong opinion. "If the system advised by Mr. Neville is adopted, that is, the use of sluices and movable weirs, a great improvement will be effected. It is quite plain that, with fixed weirs only, it is impossible to regulate a river such as the Shannon." He need hardly say how desirable it was under those circumstances that the application of some system of movable weirs to the Shannon should be duly considered by the authorities responsible for that river. With respect to the plan of the hydraulic brake shutters, one point probably occurred to everybody, namely, that those small outlets would be very awkward if they became plugged up by silt. But perhaps that difficulty could be explained away. The only other remark he wished to make was to express the pleasure with which he had listened to Mr. Vernon-Harcourt's Mr. Symons.

Mr. Symons. observations as to the desirability of having in connection with the Institution something analogous to the model room of the École des Ponts et Chaussées. He, himself, in a paper respecting the floods of 1875,[1] most earnestly appealed for the establishment of something like the École des Ponts et Chaussées, or, as he described it, an Institute for Experimental Instruction in the Laws of Hydrology. He was, therefore very much gratified to hear the present appeal for a model room.

Mr. Harris. Mr. H. G. HARRIS said that Mr. Bramwell had asked him to bring to the attention of the Institution, a model, which bore slightly on the subject under discussion. It was a model of a fish pass invented by an American gentleman, named McDonald, of Lexington, Virginia. The Board of Public Works in Virginia, had rendered it obligatory upon all authorities, over rivers in that State, to use the fish pass, of which this was a model, wherever there were any dams or weirs. A description and engraving of this pass would be found in the "Scientific American" for the 1st November 1879.

*** The replies of Mr. Vernon-Harcourt and of Mr. Buckley will be found at the end of the Correspondence.

Correspondence.

Mr. Apjohn. Mr. J. H. APJOHN observed, that during the time that the shutters of the Midnapore weir were fitted with the old gear, similar to that in use on the Mahanuddee weir, their working was most unsatisfactory. In the first place, great difficulty was experienced in the dropping of the down-stream row of shutters, in consequence of the double struts with which each shutter was fitted; as soon as one strut was knocked out of its notch the shutter got twisted, and the second strut was disengaged with the utmost difficulty. He had more than once spent all the daylight hours endeavouring, with the aid of a large gang of men, to drop the shutters, and by nightfall had only succeeded in opening half of one 50-feet-wide bay. Since the shutters were, in 1875, fitted with single struts, disengaged by efficient gear, no difficulty had been experienced in opening the sluices at any time of the day or night when the necessity had arisen, and, as at Midnapore, this might be as often as a dozen times in the season, it was essential that the shutters should work easily. At the same time that the down-stream shutters were fitted with single struts, jointed bars were

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlv., p. 1.

substituted for the chains hitherto holding the up-stream row. Each shutter (of which there were eight in a 50-feet bay) was held by two bars, each of which had a sectional area in the centre of 6 square inches, and a few even of these bars were broken during the first season that they were in use, the fracture in each case occurring in the thickest portion of the bar. This was accounted for by the bars not being quite straight; in consequence of the necessity of making them to fold down, it was not possible to have the centres of the pins in the right line passing through the centres of the cross-sections of all parts of the bar. He subsequently placed india-rubber washers 1 inch in thickness between the backs of the shutters and the cast-iron washers on the ends of the bars, and since then there had been no fractures, and the working of the gear had been everything that could be desired. Mr. Apjohn.

From data observed on the 18th of August, 1874, he attempted to calculate the strain on the chains at the moment of closing, but was not successful, as several fallacies crept into his investigation; however, the attempt had led to setting better mathematicians at work, and many different results were arrived at, the most reliable of which seemed to be those of Mr. John Elliott, then Mathematical Professor at Muir College, Allahabad, and Mr. J. S. Beresford, Executive Engineer, Ganges Canal. The former calculated the strain on the chains when the shutter was closed against a velocity of water of 12 feet per second to have been 111 tons, and the latter 62 tons. The fact of bars 6 square inches in sectional area having been since broken seemed to indicate that the higher result was the nearest to the truth. The greatest head against which the Midnapore shutters had ever been closed was 7·9 feet; this was with the old gear, and half of the chains were broken on the occasion. Although the Midnapore shutters now worked well, he certainly should not think of adopting the same system on new works, but would much prefer Mr. Fouracre's admirable plan which he had an opportunity of seeing in action when he visited Dehree in 1878.

Mr. Benjamin Baker remarked that by far the largest and most costly movable weir in the world was the Grand Barrage of the Nile, which at the same time enjoyed the unenviable reputation of being one of the greatest engineering failures, because it had cost double the original estimate, and the benefit derived from the work had not been 5 per cent. of that anticipated. The barrage consisted of two independent brick viaducts, with locks at each end, stretching across the Rosetta and Damietta branches of the Nile at the apex of the Delta. These works were founded on two Mr. Baker.

Mr. Baker. masses of concrete 1,525 feet and 1,787 feet long respectively, and 112 feet wide by 12 feet thick, the upper surface of the concrete being about 5 feet below low Nile. In the Rosetta barrage were sixty-one arches of 16 feet 4 inches span, and 41 feet high to the soffit of the arch. In the Damietta barrage there were seventy-one arches of about the same size. As it was intended to raise the low Nile level above the barrage at least 15 feet, the height of the sluices, closing the one hundred and thirty-two openings, was, from sill to crest, no less than 19 feet. M. Mougel, the engineer of the work, at first proposed to use simple wrought-iron sluice-gates, lifted by rack and pinion; but subsequently, and no doubt in consequence of the construction by M. Poirée of the segmental sluices at La Monnaie, referred to by Mr. Vernon-Harcourt, the design was altered, and sluices of the latter type were fitted to the Rosetta barrage. Mr. Vernon-Harcourt's statement that the sluices at La Monnaie were a solitary example required qualification to that extent, as by far the more important examples of the system were the sixty-one sluices 19 feet high by 16 feet 4 inches wide of the Rosetta barrage. An additional complication had been introduced by M. Mougel, in an arrangement for lifting the sluices by forcing air into submerged chambers, constituting an integral part of the segmental sluices; but the arrangement was badly conceived, and worse executed. So long ago as in 1856 the International Commission, appointed to report on the Suez canal, condemned these sluices, and subsequent Commissions in 1861 and 1863 endorsed this verdict, and recommended the substitution of an extremely clumsy system of wrought-iron girders, superimposed and dropped in grooves, like the primitive "sleeper" sluices used at the head-works of many irrigation canals. Nothing, however, had been done, and when Mr. Baker last inspected the works, the Rosetta sluices had been fitted with some half dozen different types of gearing, designed by young Egyptian engineers, the only thing noteworthy about the gearing being the extent to which the teeth had been stripped off pinions and racks. The seventy-one arches of the Damietta barrage were still closed by vertical planks, or sheet-piling, put in place, and removed each successive year.

It should have been easy to foresee the failure of the segmental sluices in the case of the barrage, because, first, there was no arrangement for holding the sluices firm, when partially lifted, and the vibration and jumping of the huge iron gates from the action of an immense volume of water rushing under the lower edges with the velocity due to a head of 15 feet, would quickly destroy the comparatively slight brick piers to which the radial

bars of the sluices were attached; secondly, no attempt had been made to secure a fairly water-tight joint between the side edges of the sluices and the brickwork. At present it was possible to pass the hand between the two at many places, and the consequent leakage under the great head proposed would certainly have left little water available for irrigation purposes. The barrage was a great engineering failure, because when the sluices were closed the brickwork began to crack, the fine sand to wash out from under the foundations, and the whole structure to exhibit a determination to move down stream long before anything approaching the intended head of 15 feet was attained. In fact, the engineers in charge of the works were almost superstitiously afraid of the barrage, and would not suffer it to do even a fraction of its intended work. With a falling Nile the water was sometimes backed up for a few days as much as 6 feet, but the average backing up was but 5 feet 3 inches, and the duration of it only about eighty days. The average quantity of water thrown into the two canals having their headworks at the barrage during this period was only 1,200 cubic feet per second, whereas the canals were intended to convey 8,000 cubic feet. Again, to obtain the full benefit derivable from the barrage, the sluices should be more or less closed for two hundred and seventy days instead of eighty only, but the engineers were afraid to leave a sluice down after the Nile had fairly begun to rise. H.H. the Khedive instructed Mr. Fowler to take the necessary steps for securing the foundations of the barrage, fitting suitable sluices, and completing the work generally at an estimated cost of about £1,000,000. The question of sluices was then very thoroughly investigated, and it was finally decided to adopt simple unbalanced wrought-iron gates, lifted by a 10-HP. engine traversing on a line of rails running parallel with the barrage. Mr. Baker had at the time the advantage of a discussion with Voisin Bey, one of the ablest hydraulic engineers in France, and the engineer-in-chief of the Suez canal throughout the whole period of its construction, about the "vertical balance gate," or "throttle-valve" type of sluice referred to by Mr. Redman and Mr. Stoney, and had arrived at the conclusion, that in hardly any case had this type given satisfaction in practice. Not a few of the irrigation canals in Egypt carried as much water as the Thames in flood, and the innumerable movable weirs on these and the minor canals consisted, without exception, of brick viaducts, the arches in which were closed by planking, reinforced at times by an earth embankment. It might be interesting to mention that a MS. account of the barrage was Mr. Baker.

Mr. Baker. presented to the Institution some thirty years ago, when the works were in progress, by M. Mougel, and would be found in the library.

M. Caméré. M. CAMÉRÉ directed attention to two articles by him on weirs, one of them communicated to the "Association Française pour l'avancement des Sciences," in 1878, entitled "Note sur le nouveau type de barrage mobile qui va être exécuté sur la Seine à Poses"; the other communicated to the "Congrès International du Génie Civil," in 1878—"Mémoire sur divers barrages en cours d'exécution en France."

Mr. Forsyth. Mr. W. FORSYTH observed that Irish rivers were small in comparison with the Godavery and other Indian rivers, and having the benefit of the equalising influence of numerous lakes, the floods scarcely ever rose more than 3 or 4 feet above the ordinary summer water-level at the weirs. The practice hitherto had been to construct the regulating, or head weirs, of stone, or stone and timber combined, and almost always without the aid of flood sluices. He was of opinion that weirs across rivers, for whatever purpose, should be constructed partly of solid masonry, with as long a line of discharge as practicable, at such a level as would allow of a rise of not more than 12 or 15 inches of flood water, and that the whole quantity of flood water in a given time, less what might with safety be passed over this solid portion of the weir, should be discharged by sluices in connection therewith. He was partial to solid permanent structures, to obviate, as far as possible, the cost and difficulty of large establishments for working and repairs. He was now engaged in preparing plans for sluices on the river Shannon, on the same principle nearly as those of Mr. Leach at Teddington. They were designed to be in bays 20 feet wide, separated from each other by piers of Portland cement concrete; in each bay were three sluices 5 feet high in the openings, separated from each other and supported by cast-iron standards, and these standards and the piers supported the rails on which the crab-winch for lifting the sluice-doors was moved. The greatest depth of water was about 8 feet, and the head for discharge from 3 to 6 feet. The estimated cost was about £22 per lineal foot.

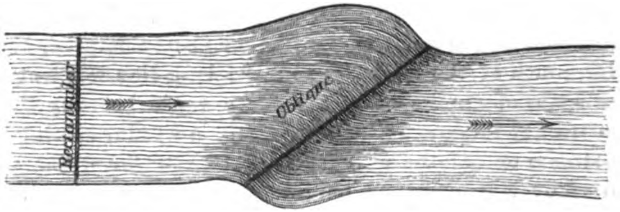
By weirs he meant solid structures of a form for allowing the water of a river to fall freely over them, so that the discharge could be calculated by the rules in ordinary use; and not masses of rubble stones which partook as much of the character of shoals as of weirs. Weirs were placed obliquely to the course of the stream, so that the length of the overfall, and consequently the discharge, in a given time might be increased; but it was stated that the

merit claimed for these weirs of actually increasing the rate of discharge and diminishing damage from floods, was inadmissible. The fact that a long line of discharge would pass more water in a given time than a shorter one needed no proof; but the facility with which the water approached and left the line of discharge was one important element in the consideration. If an oblique weir was constructed between the parallel, or nearly parallel, banks of the river, much of the advantage of the long line was lost by the confined space of approach in the acute angle between the bank and the weir at its down-stream end, and a similar small space at the up-stream end of the weir for the escape of the water after it had passed over the weir, which threw backwater upon it. This state of things arose from a want of adaptation in the approach and outfall to the motion of the water. An attempt had been made to illustrate the motion of the water in its approach to the line of discharge by a model—the river channel represented by a shallow timber box with parallel sloping sides, and an oblique weir placed between them. The water represented by a number of small glass rods, and its motion by sliding these rods forward till they touched every part of the line of discharge; but that gave an erroneous representation of the motion of water in its approach to and passage over oblique weirs. Although the filaments of the water—so to speak—might have been moving in lines parallel to the banks at a distance from the weir, yet as soon as they came within its influence they changed their course into curved lines, and passed perpendicularly over the line of discharge, a motion which could not be represented by rigid glass rods. In the rectangular weir the natural onward flow of the water was not interrupted in the same way by being bent, but approached, passed over, and left the line of discharge perpendicular thereto. But if the form of the banks of the river were made to correspond with the motion of the water, by curving the bank outwards at some distance from the down-stream end of the weir, then approaching it in a curve of shorter radius, and passing its lower end nearly at right angles to it, and again curving in the opposite direction until it corresponded with the unchanged parallel line of the river bank, the object of an oblique weir would be attained. The curve at the up-stream end of the weir was just the reverse of this; and if this form was skilfully managed, a great advantage would be gained by an oblique weir. He would illustrate his meaning by a sketch (Fig. 5, see next page). It would be seen that the water was not interrupted at the rectangular weir, but approached and left it without lateral change or motion. If the quantity of flood water to be discharged in a given time had

Mr. Forsyth.

Mr. Forsyth. been ascertained, with the height to which it could be allowed to rise, either for mill-power or navigation, without injury to the low flat land situated upstream of the weir; then the least depth of

FIG. 5.



water which could be allowed to pass over the weir, the corresponding length of the weir and rate of discharge in a given time, to pass the flood, without injury to any of the interests which might be concerned, were readily ascertained. This form of weir and weir basin, as compared with the rectangular weir, length for length, had the defect, that it must be treated as a bend in the channel, to which the same rules applied; but should an absolutely fixed height or head of water be required for mill-power or navigation, or for both, which was often the case, and the rise of the floods, on the other hand, was limited by the level of the low lands, then the true value of the oblique weir, notwithstanding the drawback alluded to, became manifest; for if the line of discharge of the rectangular weir must be lengthened so as to discharge the flood with the minimum depth of water passing over it for the reason before stated, there would be a greater amount of excavation to obtain space for it, and the greater defect of a double bend to be encountered. To ascertain the amount of curvature of the oblique weir basin, at any given point between the down-stream end and middle of the weir, the width from that point, measured on a line perpendicular to the line of discharge, must be the width of a channel sufficient to pass all the water to be discharged over the weir between that point and the lower end of the weir with the common velocity of approach due to the head. On the opposite side of the river the same process must be followed for the outfall from the weir to prevent backwater.

The majority of the weirs constructed in Ireland during the past thirty-five years, varying from 30 to 1,100 feet in length, had been more or less oblique weirs straight or curved, and not rectangular.

He was of opinion that justice had not been done to the bear-

trap sluice. If properly constructed in the first instance, it was, for suitable situations, superior to all the sluices called movable; and it was only open to one, though an important, objection, that it was costly if well constructed. The great cost arose from the piers and platforms being of first-class ashlar masonry. True it might be a temporary structure of timber; but if it was considered essential to have all the masonry connected with canal lock gates of first-class stonework, it was just as essential that the bear-trap sluice should be fitted in a similar manner; for in one view they were lock gates laid horizontally. But in these days of concrete building, the cost might be greatly reduced by the use of that material. They were suited to all heights required in the United Kingdom. He proposed constructing them in several instances, but the works for which they were intended were not carried into execution, and he had advanced no farther than the construction of a working model to ascertain their manner of operation. The bear-trap sluice had been stated not to bear comparison with the simpler systems which had succeeded it. He could not understand this statement, for its construction might be very simple, and its principal parts so massive as to have every requisite of great durability and small cost for repairs. Although not well suited to rivers much encumbered with sand, it was well adapted to the outfall of lakes, as the width of the openings might be from 20 to 25 feet without inconvenience. It might also be made self-acting by simple means. Mr. Forsyth.

He took the liberty of replying to the following statement at the end of the review of the various systems of movable weirs in Mr. Vernon-Harcourt's Paper:—"Mr. Forsyth and Mr. Manning, in their reports above alluded to, express opinions unfavourable to the adoption of movable weirs on the river Shannon." After reference to the physical circumstances of the rivers Seine and Marne, he had stated in his report of the 18th of June, 1873, that, "Considering the circumstances of these rivers, and the difficulties to be overcome, it is very probable that the principle upon which the barrages are constructed are very applicable to the case; but that cannot be taken as a conclusive argument that they are the best adapted to other places where no such circumstances exist, and where no such difficulties are to be encountered; where the rise of the floods is comparatively small, and where the locks can be passed at any state of the flood, it never being known to rise over the coping of the locks; and where substantial permanent supports of timber, iron, or of masonry can be made available for supporting sluice gates of another construction. Likewise the sluices having such

Mr. Forsyth. supports, may be made much simpler in construction, and the parts much less in number and more substantial in their dimensions.

"For these reasons I am fully of opinion that the *Barrages à Hausses Mobiles* are not so well adapted to the circumstances of the Shannon and the regulating of its flood waters as some sluices of the ordinary construction."

It was more than six years since he submitted these conclusions to the Board of Public Works of Ireland; and he was now more convinced than ever of their correctness; for since the above was written, numerous changes, and no doubt improvements to a certain extent, had been made in the dams. They seemed to be undergoing a constant change, the statement notwithstanding that they had successfully borne the test of long practical experience.

Prof. Gaudard. Prof. J. GAUDARD, of Lausanne, had read with great interest the Papers of Messrs. Vernon-Harcourt and Buckley, and finding himself entirely in accord with their conclusions, would limit his remarks to some ulterior considerations.

Of the principal types of French dams the drum system possessed the advantage, being self-acting; but it was only applicable to overfalls furnished with a fixed masonry substructure. The Chanoine dams were closed by keeping the shutters in a position parallel to the current in such a way that the resistance was small, and even availed themselves of the force of the current at the wider surface; but there still remained the need of a certain amount of manual power, and this entailed the necessity for the employment—inconvenient and sometimes dangerous—of a service barge. To avoid this, and to render working extremely easy, the tendency was towards the adoption of footways established on the top of the dam, which, supported on the movable frames of the Poirée system, might themselves be lowered in time of floods, at the cost of further manual power. Considered simply as auxiliaries, such expedients were onerous, and in the way, except when actually in use, as props for sustaining the breast of the dam. The choice, therefore, lay virtually between the primitive needle dam of Poirée and Chanoine's more recent system of movable shutters. Modifications, in the direction of simplicity, would probably be introduced for the Chanoine dam, and of facility of manipulation of the Poirée needles.

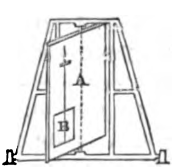
An attempt at simplification of the Chanoine system might be cited in the case of the tumbling shutters of Mr. Carro retained in place against the head of water by rods on the up-stream side instead of by props from below. This system (of which a drawing was given in M. Malézieux's "Navigation Intérieure") did away

with the necessity for trestles; but it rendered more difficult the raising of the shutters against a head of water. Prof. Gaudard.

Efforts at improving the Poirée system must be confined to the replacement of the needles by some sheathing more water-tight and easier of manipulation, which would also be available for higher water-levels, and would lessen the chance of the footway being submerged by a rapid rise. But the movable frames established in a direction transverse to the current left little to be desired. Constructed of T or U irons, they might have a height of 16 or 17 feet, while still remaining sufficiently easy to be handled. The only disadvantage in connection with them was the recess it was necessary to make in the bed of the river to receive them when lowered and partially overlapping. This recess might easily get silted up, and it was necessary to clean it before lowering, for an incompletely lowered frame would constitute a more dangerous obstruction than a Chanoine shutter, which would only present a flat surface to a boat accidently touching it.

The superposed panels, independent or articulated, abutting, instead of needles, against the movable frames of the Boulé and Caméré systems, already constituted effective improvements where there was a necessity for great height. In view, however, of avoiding the necessity of taking up the panels for opening the dam, the system of pivoting shutters, also proposed, might be preferable (Fig. 6), and that in proportion as the shutters could be easily opened by the pressure of the water. This was achieved by pivoting the shutter a little eccentrically. Further, if the footway was also formed of plates capable of being folded against the Poirée frames, as in the case of the dams on the Meuse, the whole might be laid flat on the river-bed. In closing the shutters after the frames were raised into position, it was only necessary to open a small sluice, which by diminishing the plane-surface on one leaf, enabled the water to act with greater force on the other, and so close the shutter, which could then be secured by an iron draw-bar. Such a system might be supposed to present many advantages; it would be convenient and economical, both in respect of the movable part and of the small width necessary for the masonry work on the river-bed.

Fig. 6.



The Chanoine dam was notable from the quickness with which it could be lowered from a distance, without exposing the attendants to danger in time of sudden and violent rises. But it was to be remarked that this great rapidity was much in excess of the

Prof. Gaudard. actual need, even for flushing, or rather flashing. As regarded the latter expedient, he thought flashing was only of exceptional importance. Commerce preferred a continuous service, even though it involved the delays of lockage. Besides, and above all, too frequent working of movable dams incurred the grave disadvantage of their destruction by wear and tear.

The pontoon weir might be considered as an improvement of the bear-trap system as now used at Laneuville. This latter work possessed the disadvantage of excessive friction, arising from the sliding of the top of the lower gate against the back of the principal gate. To get rid of this friction M. Krantz had hinged the two gates at their place of contact, which, of course, entailed the unhinging of one of them from the apron. From this resulted the necessity for the employment of a conduit, that the water pressure might raise the lower gate without lifting the lower edge of the principal one, which was no longer fixed to the apron.

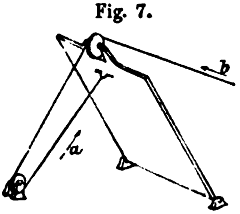
In any endeavours to classify the principal types of movable dams, it would be found at once that the governing element was ease of shutting, it being understood that the opening could always be assisted by the water, provision being made by a tripping bar, or by service sluices, &c. As to the shutting, several methods might be suggested:—(1) Manual power, exerted not only against the weight of the frames and the accessory friction, but also against the whole force of the water and the friction it engendered. This was only practicable for very small heads or currents, whether the work to be done was the flushing back of the water to raising a hinged flap, or, as was mostly the case, the cutting of the water by the drawing down of a sluice, when the dynamic pressure of the current was converted into friction in the grooves. The weight of the movable frames could either be balanced, or the whole could be used as an auxiliary to diminish the power required for shutting the sluices. (2) The power of the workman might be required still to act against the water, but to a very small extent, as in M. Chanoine's system. (3) The resistance of the water could be done away with by the provision of an auxiliary dam, or "front shutter," as was done by M. Thénard. (4) Lastly, it was possible to go further still, and to apply the whole dynamic force of the water directly to the rising of the dam. Such an application of power might be made self-acting on the water in the upper level reaching a certain point. This was M. Chanoine's system for self-regulating overfalls. But inasmuch as the action of such devices became sluggish at a certain inclination, and might, indeed, cease altogether, it was necessary to make

provision for shutting by manual power. Automatic action was only of use in particular cases, and then only for opening, not for shutting. In the form of "butterfly sluices" such contrivances were adopted in the great shutters of the Port-à-l'Anglais weir. Such butterfly sluices further constituted a safety-valve against the spontaneous or unseasonable opening of the big shutters. Prof. Gaudard

Generally the choice of the time to work the sluices was left to the dam-keeper, who would avail himself of the assistance of the water at the most opportune moment. This was the plan of M. Desfontaines, although he might easily have ordered the matter by means of an automatic float, which was also capable of application for dams such as that at Laneuville, for the pontoon weir, Mr. Fouracres' front shutter weir, the hydraulic press dam of M. Girard, &c. It was to be regretted that this last type, so simple and logical in conception, and so easy in working, cost, with its attendant mechanism, nearly three times as much as the Poirée or Chanoine dams.

As far as could be gathered from Mr. Buckley's description, the system used by Mr. Fouracres on the Sone, and particularly the ingenious disposition of the telescopic backstays of the front shutter, was remarkably well adapted for great heads of water, and was in every way suited to the Indian dams, in which, the front shutters being once closed, the workmen could have access to the flooring so as to raise the back shutters by hand. In a navigable pass, where the height of the water on the down-stream side did not allow of this access, it was a matter for consideration whether it might not be possible to supersede the repressive action of telescopic pistons by utilising the impulse of the spontaneous rising of the front shutters to open the back shutter, provided that the resistance of the latter was not great, and that the end might be obtained by bringing the shutter to a Chanoine trestles. It was true that the motion required was in a direction contrary to that of the motive power; but that was only a question of the reversal of the motion, which might be attained by the chains and pulleys shown in Fig. 7. The front shutter, in rising, would draw the fore chain in the direction a; the after chain, moving in the direction b, would raise the back shutter to which it would be attached at its end. One might proceed further in this direction, and ask if it were not possible to use a single shutter instead of two. What was demanded of the back shutter, which constituted the working dam, was that it should be lowered easily in

Fig. 7.



Prof. Gaudard. the down-stream direction under the impulse of the water, while the front shutter should be lowered in the contrary direction, so as to be easily raised by the force of the current. Might not a system of sliding sluice (*vanne circulante*), of which Fig. 8 showed the action, achieve the same end? In its normal position, A, the shutter held the water up stream, and could be lowered in the down-stream direction by slackening the chain B. Now, if the pivots fixed to the apron of the weir were adapted to slide in grooves established through the whole depth of each edge of the shutter, the latter being bedded to A′ could, by hauling on the same chain, be slid into the position A″ in such a way as to transfer the pivoting axis from one end of the shutter to the other. When in the final position, A″, the raising might be effected by the undertow of the water. The recoil from A′ to A″ might be facilitated by furnishing the shutter with rollers on rails fixed in the apron. Further, if the section of the shutter were made double convex, as in Fig. 9, and seated on an apron with corresponding concave curve, pitched at a small angle from the horizontal, gravity alone would suffice to effect the motion from A′ to A″.

Fig. 8.

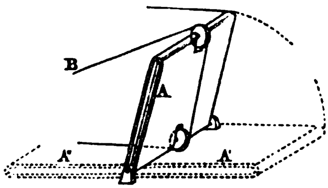
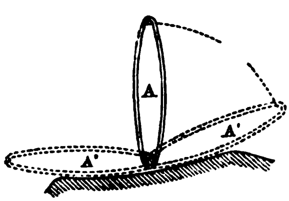


Fig. 9.



The embankment of rivers had been rightly criticised by Mr. Vernon-Harcourt, who preferred the widening and deepening of the bed. But the question was, how far could that expedient be carried without entailing prohibitive cost? It would seem that as long as the present state of things subsisted, in which most rivers were the carriers of immense quantities of silt and gravel from the mountains to the sea, the task of incessantly renewing their beds would be as pitiless as the labour of Sisyphus.

Mr. Harrison. Mr. John Thornhill Harrison observed that some years ago he had occasion to consider carefully the action of the weirs on the Thames, Severn, and other rivers; he therefore ventured to offer a few remarks on the subject. One great advantage of fixed over movable weirs was that they were self-acting. True, Mr. Vernon-Harcourt pointed out that movable weirs might be "to a certain extent made self-acting;" but the movable weirs which he described were not generally so, and when required to be moved by manual

or other labour they were open to serious objection. They were at times kept shut until mischief was done, or they were opened without proper notice being given to those who had charge of the weirs below, and serious injury was done by the artificial flood thus created, and the water overflowing the lands below. There was a notable case of this mischief at Great Marlow. Mr. Harrison.

Fixed weirs, properly constructed, were not liable to such contingencies. The prevention of land-flooding on many rivers in England had become a matter of urgent importance, and the great question was, could these floodings be prevented without interfering with, or doing away with, the navigations and the mills, for the benefit of which they were employed? His conviction was that fixed weirs, properly constructed, in connection with those river-improvements necessary for navigation, and desirable even for mills, deserved the merit claimed for them "of actually increasing the rate of discharge and diminishing damage from floods." He could not agree with Mr. Vernon-Harcourt that "theoretically it might be desirable to restore the rivers to their natural condition, and give the river-bed a fall corresponding to the fall of the land." Rivers were great powers, and too valuable to be so dealt with, and the remedy would not be effectual; it was better to reform the artificial works than to destroy them. One important effect of fixed weirs in connection with river-improvement was to expedite the transmission of the flood-water from the upper to the lower reaches, and thus to postpone the period of the maximum flood. Another effect was that they passed a larger volume of water, before the banks were overflowed, than the river would carry were all the weirs removed and it were left in its natural condition. The simple questions to be dealt with were the volumes of water which a river of a given cross-section and inclination could carry, and the volume which a weir could discharge when water passed over it at various depths.

The equation for the former was $D = A \times 55 \sqrt{HD \times 2F}$,

when D = discharge in cubic feet per minute.
A = sectional area of river, in square feet.
HD = hydraulic mean depth, in feet.
F = fall, in feet per mile.

The equation for discharge, over a fixed weir 1 foot wide, was—

$$d = 214 \sqrt{h^3}.$$

then d = discharge, in cubic feet, per minute.
h = height from top of sill to true surface of the water.

Mr. Harrison. The discharge of a river was due therefore to its fall and to its sectional area. The former could not generally be altered, excepting in cases where the river was tortuous and its course could be straightened. The sectional area, on the other hand, could be altered to any extent, either by widening and deepening the channel, or by raising the banks. Circumstances must determine in each case which of these methods should be adopted. It might fairly be admitted that the construction of a fixed weir across a channel which remained otherwise in its natural condition must form an obstruction to the free flow of the river, and must increase the liability to flooding. Many weirs were thus most mischievously constructed; and he concurred with Mr. Vernon-Harcourt that many existing weirs must be altered if the flooding of rivers in England was to be prevented.

But the improvements effected on the River Severn, by the late Sir William Cubitt and Mr. Leader Williams, were by no means of this obstructive character. They were essentially improvements, not only as affecting the navigation, but as diminishing the flooding of the adjoining lands. The floods on the Severn were less frequent and less extensive than they were previously. He had seen the Severn, in heavy floods, running over one of the weirs, when it was quite impossible to determine the position of the weir by any visible irregularity on the surface of the water; the banks were not flooded either above or below the weir, and the weir was not offering the least obstruction to the free flow of the river. The test of a weir being an obstruction was that, whilst there was a fall over it, the lands above it were flooded; if there was no visible fall at the weir, it was pretty clear that the water could not pass onwards below the weir more rapidly than it was discharged over it. The peculiarities of the Severn improvements were that the river was nearly doubled in width at the points where the weirs were placed obliquely across this widened channel, so as to be in length about three times the width of the river in its ordinary condition. The best weirs were built with a nearly upright face on the upper side and an easy slope on the lower side; thus the deep water was continued up to the back of the weir. Again, the bed of the river was deepened upward to the next weir and lock, so as, in dry seasons, to maintain a sufficient depth of water for navigation between the locks. A river thus judiciously improved by deepening and the construction of weirs might fairly "claim the merit of actually increasing the rate of discharge and diminishing damage from floods." In the first place, this condition of a river was well calculated to transmit with

rapidity the water of the rising flood. The ordinary flow of water in some rivers was so small, and the rapidity with which the rain-water descended from the steep highlands so great, that the flood rushed down the river in the form of a bore, the water in the channel being altogether insufficient to transmit it. This was notably the case in the River Ure, in Yorkshire. It not unfrequently happened that there was little or no rain in the lower reaches of the River Ure, when rain was falling in torrents over the hills to the westward, and there was no intimation of the approaching flood until the bore came tearing down the channel. It was most probably owing to such an unexpected and rapid rising of that river that the son of the late Dean of Ripon lost his life a few years ago. The Ure was an extreme case, but in many other rivers the circumstances were similar. Now, a river divided into reaches of deep water, with an ample length of weir at the end of each reach for passing the water onwards without materially raising its level, was well adapted to transmit the waters of an increasing flood with great rapidity towards the lower reaches of the river. This facility of passing on rapidly the flood-water was of great importance. It might occur that a rainfall which would, under ordinary conditions, cause a slight, but still injurious, flood in the upper reaches of a river, might thus be passed onwards without occasioning the slightest injury. Again, when heavy rains were long continued, and the channel of the river was nearly filled, the improvement was still beneficial, the increased depth of the water below each weir increased the sectional area and the hydraulic mean depth, and consequently it required a less inclination of the surface to give the requisite velocity to the water at that point. As the water flowed onwards it passed into a channel of gradually diminishing sectional area, and the inclination of the surface of the water was necessarily increased so as to give the requisite velocity until the next weir was approached, when the low level maintained by the action of the weir afforded a greater inclination to the water-surface than that of the actual fall of the river. At some intermediate point the inclination of the water would coincide with that of the banks, but at that point the sectional area and the hydraulic mean depth being greater than those of the river in its unimproved condition, this discharge would be correspondingly increased. Even when the weir was out of work, the inclination of the water-surface below the weir would be less than that above it, and would give the requisite increased velocity, although such variation in inclination might be imperceptible to the eye. Mr. Harrison.

Mr. J. Clarke Hawkshaw observed that movable weirs and fixed Mr. Hawkshaw.

r. Hawkshaw.

weirs had each their own special advantages, and the question as to which should be adopted in any case could only be determined by circumstances. A fixed weir across a river, whether obliquely placed or not, must at all times be an obstruction to the flow of water in the river; whereas some movable weirs presented no obstruction whatever in flood time. On several English rivers it was necessary for agricultural purposes to maintain the summer level of the water at very little below that of the surface of the land. In such cases he considered movable weirs preferable to fixed weirs; for with fixed weirs the sill of the weir had to be placed so high that embankments became necessary to keep the flood water off the land, whereas with movable weirs the flood level could in most cases be kept below the level of the land by enlarging the river channel.

The lightness of the frames of some of the weirs erected in France was very striking, and it might seem unnecessary to make the frames themselves movable when the obstruction which they offered to the flow of water had been reduced to a minimum. But that they should be movable was, he thought, an important provision, as it ensured the whole section of the weir being available for discharge. The frames might not offer much obstruction in themselves, but they might do so to a great extent by holding floating objects brought down by floods. A serious flood occurred at Norwich in November 1878, by which part of the town was laid under water. Though the flood was owing to insufficient waterway being provided at the mill weir above the town, it was rendered much more disastrous owing to the waterway, which consisted of a number of openings, being in a great measure blocked by rubbish, old boats, timber fencing and hay brought down by the flood waters. It was obvious that a larger waterway, that was a larger weir, must be provided, when it was liable to be obstructed in flood time, than need be provided when the frames of the weir were movable, and the whole waterway could be relied on as available.

On the rivers that he had examined during the last few years, with a view to ascertain the best means of preventing floods, he had found a rule that the existing weirs and sluices were inadequate for the discharge of flood waters, and that if floods were to be prevented, a great number of weirs would have to be rebuilt or enlarged. There was little chance of English rivers being comprehensively dealt with at present, owing to the divided jurisdiction they were under, to want of funds or power to raise them by rates; but when the long-looked-for Conservancy Bill passed, if it should prove effectual, and existing weirs had to be rebuilt,

engineers would have reason to thank the Authors of the Papers for the information on weirs which they had so ably provided. Mr. Hawkshaw.

Professor J. Hirsch, of the École des Ponts et Chaussées, Paris, had read the Papers of Messrs. Buckley and Vernon-Harcourt with great interest, and was much struck with the clear and lucid account given by the latter of the principle types of movable dams used in France. The advantages of M. Poirée's needle weir were being daily more appreciated by engineers engaged in constructing or in maintaining river works, and he was glad to find that Mr. Vernon-Harcourt was of the same opinion. On the whole, the Author's views appeared to be based on a thorough knowledge of the subject, and were enunciated with a clearness and precision that could not be too highly praised. Professor Hirsch would therefore confine his remarks to a few points of detail which had doubtless escaped the Author's attention, or on which, perhaps, his own knowledge of English was insufficient to enable him to grasp the exact meaning. In discussing the remedies to be adopted in cases of river floods, and preventing them from producing disaster, as at Szegedin, the Author rejected longitudinal embankments as inefficient and dangerous, and recommended the widening and deepening of the bed. Professor Hirsch thought this should be taken with some reservation. The dangers of longitudinal embankments had long been acknowledged; they were liable to be surrounded, undermined, or overtopped. It would be better that they should be perforated before the flood, that they were intended to restrain, had reached its greatest intensity, although such a proceeding seemed to involve the paradox that a longitudinal bank was more dangerous in proportion as its construction was solid. The mode of meeting this difficulty, advocated by the Author, was doubtless preferable, but it was to be feared that, in most cases, it was impracticable. It would at least be so in the case of most of the French rivers. To regulate the course of a river by dredging and clearing the bed, it was necessary that the work should be carried throughout the whole length, and that the solid matter brought down by the current should be removed every year. Even for unimportant streams the quantity so to be dealt with was so enormous that it would be in excess of all the means of removal at command. In such case the river beds and the bottoms of the valleys would progressively be raised by atmospheric action—filled up by the material brought from the mountains. This was one of those great natural phenomena against which the forces of man were powerless, and against which it was useless to contend. Professor Hirsch was never- Prof. Hirsch.

Prof. Hirsch. theless willing to allow, that although local works and dredging did not afford a general solution of the problem, they presented in some special cases the best means to accomplish the end in view.

Five dams had been recently constructed on the Saône for the improvement of the navigation between Verdun and Lyons. Each of these works included a large lock, a navigable by-pass, and an overfall. The navigable pass, 164 feet wide, had its sill 11½ feet below the water-level; the latter was formed by Chanoine shutters, with a service bridge supported by movable frames. The overfall consisted of a shutter and needle dam, and the sill was 8¼ feet below the upper level of the water. These works ensured at all times a depth of 6½ feet of water for a length of 105 miles of river where it was needed.

The information contained in Mr. Buckley's Paper relative to the Indian rivers was new to him, and was extremely interesting. Not knowing the data of the streams for which the works were constructed, it was difficult for Professor Hirsch to offer any remarks of value. In regard to this he had some doubts of the superiority claimed by Mr. Buckley for the system of dams described on page 52. In the first place, the Poirée dam was capable of being provided with gear that allowed of its being opened with extreme rapidity on rivers subject to rapid rises. This system had been successfully applied in a large number of cases, especially at the great dams on the Lower Meuse, in Belgium. Further, the property of acting automatically when the water-level rose became occasionally dangerous, as had occurred on the Upper Seine. Engineers of great experience preferred to retain the control of the dams rather than abandon them to automatic action. Otherwise, nothing was simpler, when the necessity arose, than to render most of the systems of movable dams self-acting. In the third place, movable dams of all types could be closed under large heads of water. He would add, that the system of dam mentioned, which involved stone piers placed at intervals of only 20 feet, would be utterly inapplicable for the majority of French rivers, where openings of 100 to 200 feet free of all obstruction were indispensable.

Mr. Manning. Mr. Robert Manning begged to observe that the statement made in Mr. Vernon-Harcourt's Paper, that "Mr. Forsyth and Mr. Manning, in their reports above alluded to, express opinions unfavourable to the adoption of movable weirs on the river Shannon," was inaccurate. At page 30 of his report he expressed an opinion that the principle, at least of three of the movable weirs described,

Mr. Manning.

was applicable in the case of the Shannon; and in the last paragraph of the report he stated that, "If the dimensions of the channel be enlarged by an adequate quantity of excavation, then any one of the three sluices I have named—or perhaps one equally efficient, but more simple and cheaper than any of them—may be applied with success to ths regulation of the flood waters of the Shannon." The substantial question raised in the year 1873, and previously, was the application of the *barrage à hausses mobiles* of M. Chanoine to the drainage of the Shannon; this Mr. Manning was unable to recommend, for the reasons stated. The opinion then formed he still held, and was confirmed in it by M. Boulé, who erected the new pass at Port-à-l'Anglais on the Seine in 1870. That engineer (who had full opportunity of observing the working of the system) condemned it as most expensive and complicated, with fragile parts always under water, whether the dam was open or shut, and as most difficult and expensive to maintain. He had substituted for it a new system, which had been ordered by the French Government to be adopted at Port-Villez, on the Lower Seine.

Mr. McKie.

Mr. H. U. McKie remarked that extensive land drainage, and the better cultivation of land had so diminished the minimum and increased the maximum flow of rivers in England, and consequently made the water power of comparatively so little value, that it would be an advantage to the land adjoining, as well as conducive to the health of the inhabitants living near, if a great number of the weirs were altogether removed. In consequence of the improvements in transit since the mills were erected, and the decrease in the price of fuel, steam power in most cases would drive mills more economically than water power, which, with few exceptions, was uncertain and unreliable, and in many cases had to be supplemented by steam power, as otherwise the mills and extensive buildings and premises adjoining would have had to be abandoned altogether, and in other cases, where not so supplemented, they had been actually disused. He had heard a statement that the law expenses incurred as to water rights in Lancashire had been far greater than the value of the whole water-power in the county. There were, however, some fine examples of engineering in England in the weirs erected for water-power, particularly in the north of England, such as the Holmhead bay, and Dalton bay, on the Calder, the former of which was designed by Mr. Bateman, Past-President. The subject was one of importance, as weirs would, for one purpose or another, be always required; but he thought that their time for power or navigation

Mr. McKie.

had gone by; steam would better supply the former purpose, and if it were necessary that navigation should be kept up in some valleys, he believed a canal would much better answer the purpose. He could not agree, as had been suggested, that the embanking of rivers beyond the tidal portion of their course was unadvisable. As far as his experience went, embankments above tidal level were of great value when judiciously carried out, with a due regard to the watershed, rainfall, and other local considerations. In the Eden and the Calder, for instance, the water sometimes rose from 15 to 20 feet vertically in as many hours; and it was necessary to preserve the land below that level from being injuriously flooded, and from great damage being done to property and health. He admitted that injudicious embanking of rivers could have but one result, and that a disastrous one. As in many cases rivers were the boundaries of properties, it would be often found that proprietors, without taking advice, or going into calculations as to the discharging power of the waterway, only appeared to have one idea, and that was to make their embankments as near the river as possible, the consequence being that in the next extraordinary flood both properties, as well as the land adjoining, were flooded. As to the advantage of banking out rivers, he might instance Carlisle, which used to be subject to disastrous flooding in the lower parts of the city, but had not once suffered from this cause since it was protected by river embankments; if the embankments were removed, about a fifth of the city would be flooded in case of an extraordinary large flood, such as he had seen in the Eden.

Lieut.-General Rundall.

Lieut.-General F. H. Rundall, R.E., C.S.I., observed that, in discussing the subject of river weirs, it was necessary at the outset to recognise the impossibility of prescribing any one model for universal adoption. The design in every case must be governed by the specific conditions encountered in the locality to be dealt with. Thus, not only must the characteristics of the river itself be studied, but the materials locally available; the influence of climatic or atmospheric changes on those materials; their exposure alternately to great heat or cold, with various other conditions, must be taken into consideration. A class of works, and details of design that might be suitable for rivers in India, would probably not answer for rivers in France or England. For example, the rivers in India alone across which weirs had been thrown presented the following widely different conditions:—

1. Beds of either solid rock, or rock intermixed with hard soil, sloping at the rate of from 5 to 6 feet per mile.
2. Beds of uniformly hard clay, with a similar declivity.

Lieut.-General Rundall.

3. Beds with a surface of sand overlying a stratum of clay, with a less slope.

4. Beds of large-grained sand intermixed with pebbles, with a declivity of from 2½ to 3 feet per mile.

5. Beds wholly composed of coarsish sand to a great depth sloping from 1 foot to 2 feet per mile.

6. Beds of exceedingly fine sand resembling flour, with a declivity of from 4 to 12 inches per mile, between banks of very friable material.

7. Beds composed entirely of boulders, with a very steep fall, varying from 15 to 30 feet per mile.

Each of the above-mentioned varying conditions was further accompanied with great differences in the height, duration, and behaviour of the periodical floods. Hence it would be obvious that each river must be treated distinctly, according to the peculiarity of its characteristics.

Again, in India all wood and iron work were exposed alternately to submersion in water, and then to an excessively dry atmosphere, and to the fierce rays of a tropical sun. In England, on the other hand, all materials were subjected to the effects of cold. Such differences rendered it difficult to apply the experience gained in either country to the other. Certain points were, however, common to all structures of the kind under discussion, which demanded particular attention; such as, the trials to which submerged weirs were subjected at various stages of the floods, and the effects produced on the regimen of the river. Where the object of a weir was simply for the improvement of the navigation, a different kind of work was required to what would be constructed for the purpose of supplying a canal or driving a mill. In India, the necessity for preventing as far as possible accumulations in the bed on the up-stream side, rendered obligatory the combination of open sluices with the permanent weir. When such sluices were situated at the flanks of the weir, the manipulation of the gates presented comparatively little difficulty; but when situated in the middle of such long weirs as those in Orissa and the Sone, special arrangement and mechanism had to be devised. Mr. Buckley's Paper clearly described the different expedients resorted to on the Indian weirs. A combination of the French needle dam, with the modifications suggested by actual experience in Orissa and the Sone, would seem to afford a likely model for open weirs on small rivers like those in England, where improvement of the navigation was the immediate object in view. As an instance of the successful working of sluices with falling gates, he would

Lieut.-General Rundall.

quote the river Beropa, one of the smaller branches of the Mahanuddee, in Orissa. The weir which spanned the Beropa was 2,000 feet long, 9 feet high, and submerged 10 feet during extreme floods. It was furnished with two sets of sluices at either flank, each containing 100 lineal feet of waterway, fitted with falling gates of a pattern similar to those on the Mahanuddee weir. Although the distance of the Beropa weir from the bifurcation at the Mahanuddee weir was more than a mile, the scour produced by the sluices along that distance had been sufficient to maintain a clear channel for navigation to the head of the canals, which was conducted from the weir on either flank. Several modifications of the French pattern were found necessary before the gates worked satisfactorily, but he believed they had for some years proved perfectly manageable and effective. He had little doubt that the system of falling gates used on the Sone weir, as improved by Mr. Fouracres' inventions and adaptations, embraced almost all that could be desired, and, *mutatis mutandis*, would be found applicable to the requirements of rivers in England generally. The regulating dam across the arm of the Ganges, which supplied the great canal at Hurdwar, was of simple construction.[1] This model of dam might, with some minor modifications, be also found suitable to English rivers.

The important subject of the disposal of flood waters in this country had been introduced by Mr. Vernon-Harcourt. It would be impossible to prescribe any definite treatment for universal adoption. The system of embanking, the merits of which had so often been discussed and disputed, had nowhere—not even in Italy—been carried out so extensively as in the Indian deltas. The objections so often urged, and which Mr. Vernon-Harcourt had repeated, that the embanking of rivers caused a rise in their beds, was, however, not borne out by his own experience. So far from that, the result of a proper and scientific system of embanking regulated and rectified the regimen of a river, and tended to equalise its sectional area. As a delta river extended seawards, its declivity decreased; but as the volume of its floods was in nowise diminished, there must needs be an increase of the sectional area to ensure its discharge. If, therefore, the width were maintained uniform by embankments, the depth must increase; and if the velocity was insufficient to scour the bed, the surface level of the flood water would rise until the increase in the surface slope, combined with the increased depth, secured the requisite velocity. This rising of the flood surface

[1] *Vide* Plans No. XIV. in the Atlas, illustrating Sir Proby Cautley's report.

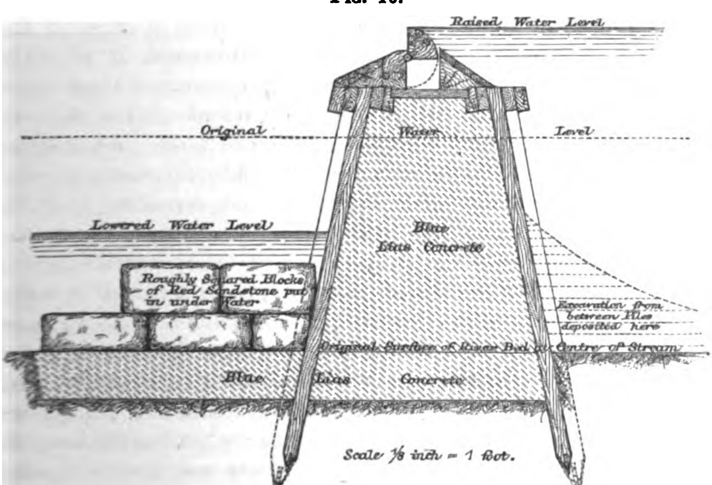
Lieut.-General Rundall.

had probably led to the idea that the bed of an embanked river became raised. The river Po, which was usually urged as an example, had been shown by Messrs. Humphreys and Abbot, of the U.S. Engineers, on the authority of Lombardini, not to have raised its bed at all.[1] It was to be hoped, then, that before deciding on any definite scheme for dealing with the floods of the rivers in England, the subject would be carefully and comprehensively considered by a commission of engineers of special experience in this difficult branch of engineering. He would not enter into any details, as he had already treated the subject of weirs at some length in a series of lectures delivered in 1875, at the School of Military Engineering at Chatham. In those lectures would be found some particulars of irrigation works in general, and of weirs in particular, which perhaps might not yet have been described by other engineers who had read Papers at the Institution, and which might prove useful to members of the profession exercising, or who might be called hereafter to, an Indian career.

Mr. Sandeman

Mr. J. WATT SANDEMAN described a new form of weir that he had constructed at Barnton, on the river Weaver navigation, in 1873. The weir was of timber and concrete (Fig. 10); a

FIG. 10.



double row of main piles, 8 feet apart from centre to centre,

[1] *Vide* Report upon the Physics and Hydraulics of the Mississippi River, p. 412.

Mr. Sandeman. being driven across the stream, and between these 6-inch sheet piling. The ground inside was excavated to about 4 feet below the level of the original river bed. Upon the lower side of the weir an apron of concrete and large blocks of roughly squared stone was formed. Upon the top of the weir there was a movable cap, for the purpose of enabling ice to be flushed over, so as to remove it from the navigable channel. The cap was of pitch-pine timber, quadrantal in section, hinged on its lower edge, and was worked by two men, by capstans and worms, gearing with worm quadrant wheels, one at each end. Alongside of the weir there was a large lift sluice for the relief of flood water; it was constructed of green-heart and pine timber, and was 14 feet wide by 12 feet deep below the upper water-level. The weir and sluice had answered well the purposes for which they were designed.

Mr. Shelford. Mr. W. Shelford said that the subject was a novel one in the Institution, because the great works executed by British Engineers in India were not often described, and because in England there was no field as yet for the exercise of the engineer's ability in this respect. For the last quarter of a century it might be said that river improvement in England had been almost in abeyance. Before that time great works had been executed by such men as the Rennies, Stephensons, James Walker, Rendel and others, but these were confined to the improvement of the tidal channels. Above the tidal influence the rivers had been made into canals in the last century, and now, owing to the competition of railways, these navigations were worthless, and did not even pay for their maintenance, so that the natural consequences of the deposit of detritus, growth of weeds and general neglect, had been to deteriorate the rivers of this country, as channels of flood discharge, to such an extent, that they were inferior to what they formerly were, notwithstanding that the country had in other respects, greatly advanced and improved. Mr. Vernon-Harcourt had proposed as a remedy to widen and deepen the channels, and to construct weirs of modern type. This would be a continuation of the works of the great engineers before mentioned, whose fundamental principle was to deepen the channels from the outfalls upwards. But this mode of improving rivers was modern in this country, and even now was not adopted in some countries on the Continent. In old times the fen-men in England banked out the floods from their land, instead of deepening the channels; and in Japan the same thing had been done for centuries, and the banks had been raised as the beds of the rivers rose until the latter were

now 40 feet above the country, and railways were carried under them by tunnels instead of over them by bridges. In China, too, a case had been reported, where a river had burst its banks and made a new channel at a lower level, and the old bed had, owing to its height, served for a refuge for the inhabitants in floods. In more recent times the Po was an example of the same thing, and the Tiber was at the present time undergoing improvement by the construction of embankment walls through the city of Rome, with the object of banking out the floods, so as to avoid lowering the bed. He had lately visited the Tiber, for the purpose of examining its capability of improvement, and he had found that of all the numerous propositions which had been made for that purpose, none had attempted to deal with the outfall, though some of them had contemplated a deepening of the river through Rome, and lowering the level of the water: but so far they had been rejected by the Government, after careful consideration. No doubt the difference in practice between Italian and English engineers was due, in great measure, to the fact that Italian rivers ran into tideless seas, the effect of which was, as between the Tiber and the Thames, which above the cities of Rome and London might be fairly compared with each other, to produce an insignificant channel below Rome capable of floating vessels of 100 tons only, as compared with the grand river, or rather estuary, below London. If such a river as the Tiber were to be improved, or if the upper portions of our own rivers were to be properly treated, he was of opinion that movable weirs, in some form or other, would play a prominent part; and if the legislature would assist in reconciling the conflicting interests of the parties having the water rights, a wide field would be open to engineers for their application in this country, as he understood there was already in India. Mr. Shelford.

Mr. J. H. Taunton remarked that the navigation on the upper Thames between Lechlade and Oxford, a distance of about 30 miles wherein there were but four locks, had ever since its existence been mainly dependent on weir constructions such as those described by Mr. Vernon-Harcourt. Since the conservancy of the upper river had passed into the hands of the Thames Conservators in 1866, many of the old movable weirs had been taken down, and the river at various places, such as at Radcot, Tadpole, and Standlake, immediately below which places the old weirs had been removed, had in consequence ceased at ordinary times to be navigable for any boats carrying cargo. Mr. Taunton.

Where the old weirs had been left, as at West weir, Cocks weir,

Mr. Taunton. Langley weir, and Ensham weir,[1] the navigation might in a rough way still be carried on and continued as heretofore, that was in flashes for descending boats, the weir openings being kept up during their passage and whilst they worked over the pound below, but being shut and closed for ascending boats immediately after getting through them. These weirs were of ancient and primitive construction, consisting usually of one or two openings 14 to 16 feet wide, with large doors or sluices to fit, raised and lowered by tackle, or sometimes of a series of paddles 1 foot 6 inches to 2 feet wide, running between "rimers" or movable posts which stood when in place on the sill of the weir, such paddles being hand raised. It was certainly unfortunate that navigation throughout one of the principal rivers of this country, the preservation of which for centuries past had been the subject of continuous legislation, should have ceased to be practicable under recent legislation, and the management of the authorities in present charge of it. To these authorities, by the Act of 1866, were committed the care of the weirs, with large funds from the Water Companies of London, *inter alia* for the maintenance and improvement of the navigation works. They had hitherto, in the discharge of their trust, so far as the navigation of the upper river was concerned, removed some of the old works without substituting others in their place, and thus had effectually stopped the navigation of the Upper Thames for trading vessels within its ancient limits. It was the more unfortunate as they were a paid body, with a delegate from the Board of Trade in their councils, and they had managed since 1866 to expend a very large sum of money fruitlessly, so far as the through navigation of the river as formerly was concerned. As to the value of movable weirs of the character described by Mr. Vernon-Harcourt, there might be cases where they proved useful, but for navigation purposes, with the idea of vessels passing through them, many grave objections arose to their use. In most applications their character as mere "expedients" became manifest, whilst in a general way their economy over more substantial constructions was somewhat doubtful.

Mr. Unwin. Mr. Howard Unwin, having had charge for several years of the practical working of the system adopted on the Mahanuddee and Cossye rivers as described by Mr. Buckley, would add to the list already given the weir on the Beropa river, and the second weir on the Cossye river at Panchkorah. The former river branched

[1] *Vide* "The Oarsman's and Angler's Map of the River Thames." Published by James Reynolds, 174, Strand.—J. H. T.

off from the left bank of the Mahanuddee, about ½ mile above the great weir, and the site of the weir on the Beropa river was about 1 mile below this junction. The crest was 1 foot below the crest of Mahanuddee weir; it was constructed for the purpose of supplying water to the high-level canal on the north or left bank of the river, and to the Kendrapara canal on the south or right bank. At the northern end of the weir, which was built on the solid rock, the scour was maintained by vents 5 feet wide, closed by timber gates sliding in vertical grooves, which were removed by manual labour. The southern end of the weir was built on wells sunk in the sand, and adjoining the head sluice of the canal, a movable dam, 120 feet in length, was provided with wooden shutters, as described by Mr. Buckley on Plate 4, Figs. 1, 2, and 3. The opening was closed by twenty shutters, each 6 feet in width, the gearing for working ten shutters being fixed on the shore abutment, and for the remaining ten shutters on the pier adjoining the crest of the weir. He had charge of the working of these shutters from 1872 to 1876, and during the flood season, lasting from June to October, they were raised and lowered without any practical difficulty. Now and then a chain on the front shutter would give way, generally due to a faulty link, and on one occasion a back shutter was carried away; but by temporary expedients the utility of the movable dam was secured, and after the flood season the permanent repair was effected. The annual cost of maintenance was not excessive; the actual figures could be obtained from the accounts of the division. The advantage due to the free scour of a stream of water 120 feet wide, and full depth of the flood, would be readily understood; the only objection being the extra cost of throwing up a ring bund in front of the shutters during the dry season, so as to lay the floor dry for the purpose of repairs; on this account, openings of 50 feet or less would be more economical, and these might be closed one by one for repairs by a floating caisson fitted against the cutwaters of the piers. An arrangement of this description had been proposed, but in those days money was not available for the Orissa works. Mr. Unwin.

On the Cossye river the second weir was at Panchkorah, about 50 miles below the main weir at Midnapore. It was only 332 feet long between the abutments, with a movable dam of 50 feet in length at each end of the weir. These openings were closed by folding shutters on the Mahanuddee system; but in practice, the regulation of the water was effected by using one opening on the left bank, the shutters in the other being kept up. From personal experience during the last flood season, June to October 1879, it

Mr. Unwin. could be stated that these shutters were worked most effectively without the slightest hitch. Owing to the contracted section of the river at Panchkorah, a rise of 1 foot of flood at Midnapore produced a rise of 4 feet at this weir. The freshes were, as a rule, numerous and sudden, and the working required the close attention of an efficient European subordinate. It had been found necessary to both raise and lower the shutters within twenty-four hours, and frequently the operation was performed at night.

At the Midnapore weir the regulation of water was also effected by using one opening of 50 feet, the other two openings remaining closed. In addition to the movable shutters, the crest of the weir for 1,200 feet and 300 feet was provided with iron grooved stanchions 10 feet apart, and 2 feet and 4 feet high respectively, in which planks 6 inches deep were placed by manual labour. The top row of planks was 82·5 feet above datum, the sill of the shutter being 72·0 feet, and the top of the shutter, when raised, 81·5 feet. The man in charge was instructed to drop the shutters on a rising fresh when the water had risen to 83·0 feet above datum, that was 1 foot 6 inches over the top of the shutter. As far as possible the water was held up by the planks on the crest of the weir, and the intermediate regulation was effected by them so as to avoid the too frequent working of the shutters. After a fresh had passed down, and the water had fallen below the minimum depth, the shutters had to be raised, care being taken that the front shutters were not released with the water more than 80·5 feet above datum; as, if a sudden rise in the river took place before the back shutters were raised, and the front shutters properly hooked down, it would be impossible to drop the shutters, and the result would be a great accumulation of silt, and probably a stoppage of some weeks until the silt could be removed by manual labour. In raising the shutters the first operation was to remove the planks from the crest of the weir to pass off as much surplus water as possible. The disengaging gear of the front shutters was then worked, and in a few minutes the eight shutters of the 50-feet opening flew up into a vertical position. The back shutters were then raised by being hauled up one by one by a chain worked from a crab-winch fixed on a 50-ton barge moored in front of the line of shutters; the end of the wrought-iron strut behind dropped of its own accord into a recess on the floor as soon as the shutter was vertical. This operation was completed in two or three hours. The front shutters were then hooked down, and it was sometimes a tedious business, as the men were working up to their necks in water, and had to dive down to remove any silt or gravel which

Mr. Unwin.

prevented the shutters from lying perfectly flat. After they were all in position, being weighted by a piece of kentledge, the disengaging gear was worked, and the hooks retained the shutters ready for the next operation. The working of the shutters took from ten to twelve hours, and the permanent establishment consisted of fifteen lascars, with a few extra coolies during floods to secure the planks on the weir. At all times it was a matter of anxiety to those in charge in case a sudden fresh should come down in the middle of the operation; but for some years, it had been carried on successfully, and during the past season the shutters were worked without the slightest hitch or injury on the following dates:—

Shutters lowered.	Shutters raised.
July 11th.	July 15th.
August 6th.	August 21st.
September 25th.	October 2nd.

The season was unusually dry, the rainfall having been 30 inches against an average of 56 inches, and there were no severe floods in the river. The folding links, in place of chains, for the front shutters had never failed, and the maintenance charge on this weir was comparatively trifling.

The arrangement of a movable dam on an Indian weir was of the utmost importance. Without it, neither a navigable channel to the head lock, nor a sufficient supply of water to the head sluices of the canal could be maintained. During last flood season the daily supply required was 1,000 cubic feet per second, and frequently the whole of the water in the river had to be sent into the canal, while in the course of a few hours 30,000 to 50,000 cubic feet per second would be passing over the weir. In the dry weather the shutters and planks were carefully caulked with hemp and straw, and not a drop of water was allowed to pass the weir. It might be noted that the length of movable dam on the Beropa river was 120 feet, and on the Cossye, three openings of 50 feet each, but only one of them in use. This was due to the construction of a training groyne of rough rubble stone, from the abutment of the movable dam at right angles to the line of weir, forming a defined navigable channel 200 feet wide for about ¾ mile in length. In the Beropa river no such groyne had been made, and of course the action of the scour was not so concentrated. No general rule, however, could be given for the correct proportion of movable dams compared with length of weir, each particular case must be settled on its merits. Before the Mahanuddee system of shutter could be successfully

Mr. Unwin. worked in a cold climate, several improvements would have to be introduced, as the present method of working was only possible in water of a comfortable temperature.

Mr. Walker. Mr. JAMES P. H. WALKER remarked, that the subjects treated of in the two Papers were of much and increasing interest and importance to English engineers who had to deal with weirs on a large scale on Indian rivers. Mr. Vernon-Harcourt had very properly drawn particular attention to the different systems of what he termed "movable weirs," so generally in use on the rivers in France, and he thought the thanks of the Institution were due to Mr. Buckley for his description of the various forms of shutters introduced of late years on the weirs built across Indian rivers.

Various and serious disadvantages resulted from the small sluice vents of from 5 to 6 feet in width, with intermediate masonry piers, which were at first generally adopted for the long complete weirs constructed in the deltas of Indian rivers. One main and obvious defect of these small sluices was the inevitable formation of shoals above the weir, rendering the navigation of the river dangerous to boats during the freshes, and difficult during the dry months; and entailing the removal of shoals and dredging out of channels at a yearly increasing amount of trouble and expense. The loss of water for irrigation during the hot season, owing to the shoaling of the river above weir, was also a serious consideration, though one perhaps too little thought of. Its importance might, however, be better appreciated when it was remembered that in the case of a large river, such as the Mahanuddee or the Sone, the irrigation of from 30,000 to 40,000 acres of sugar cane, and other crops requiring water during the hot months, might be maintained for two or three weeks by merely drawing off 2 feet of the water impounded above the weir.

Allusion had been made by Mr. Vernon-Harcourt to the weirs built on the river Severn, and to the oblique direction designedly given to some of the works with reference to the direction of the stream. While the effect claimed for oblique weirs in diminishing damage by increasing the rate of discharge was evidently inadmissible, he believed that such obliquity or skew to the general direction of the current was inadvisable in any case, and was a radical defect when the weir was built in a river subject to rapid and heavy floods. In a large weir, of which he had charge for many years, and which he had constructed, under the direction of Major-General Rundall, R.E., across the river Katjooree, in Orissa, Bengal, the work was built with an angle of 27° of skew to the course of

Mr. Walker.

the river.[1] The weir was 4,000 feet in length, with crest 8½ feet above low water, the rise of the river in high floods being as much as 28½ feet. The current, when the river was in flood, did not strike the weir at a uniform angle, the obliquity of impact varying from 11° to 30°. When the work was first constructed, and before the river had established itself to the new conditions, the effect of the skew direction was to cause a heading up of the water at the lower or down-stream end of as much as 9 inches, though the lower end of the weir was nearly ½ mile further down stream than the upper extremity of the weir. This was the case in high floods when there was a depth of 18 feet of water passing over the crest of the weir, under a great velocity of approach; but, in lower floods, when the depth over the crest was only 4 or 5 feet, the depth of water passing over the lower end of the weir did not exceed the depth at the upper end by more than 3 or 4 inches. From the way in which the coping and crest of the weir were scored by stones and gravel carried over by the current, and from the appearance presented by the work when breached by heavy floods, it was evident that it was exposed to a serious undermining action due to the current striking it at an oblique angle.

The primary object of the sluices with which the weirs across Indian rivers were pierced was to produce a scour in front of the head sluices placed adjacent to them in the bank of the rivers for feeding the canals. They were designed, however, to serve other ends. By opening the weir sluices with the rising flood, the bed or basin of the river below weir became rapidly filled up, and the tail water, thus produced, saved the lower apron from being unduly exposed to the hammering action of the water plunging over the crest of the weir. To some extent also, but a comparatively small one, these sluices had the effect of keeping down the shoals above weir and maintaining channels for navigation. The aggregate length of sluice vents to the whole length of weir varied considerably, being from $\frac{1}{10}$ to $\frac{1}{6}$ of the length of the weir in those works with which he was better acquainted. Notwithstanding the high cost of the shutters or movable portion of the weir, as compared with the body of the work, he believed the adoption of sluices on a much larger scale than had hitherto

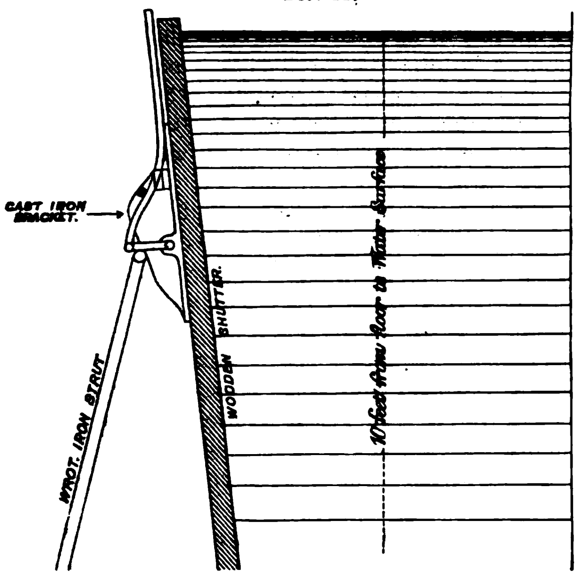
[1] This angle was not purposely given to the weir, and would certainly not so have been given to it, but for the fact of a large spur or incomplete weir having existed for several years at the site. General Rundall considered that it would prove an economical arrangement to found the weir on the existing stone spur, but experience proved that it would have been better to have built an entirely new work at right angles to the river.

r. Walker. been the practice was only a question of time and suitability in form of shutter. The evils attending the construction of long solid barriers across the river-beds were often severely felt, and once allowed to come into existence were almost ineradicable. The Authors of the Papers had therefore done well in calling attention to a subject of so much practical importance, for it must be borne in mind that the head works formed a large item in the cost of any system of irrigation and navigation in an Indian Delta.

For the last twelve years the system of MM. Thénard and Mesnager had, with some modifications, been in operation on the weir across the river Mahanuddee in Orissa, and lately it had been in principle extended to similar works of 4,000 feet, 900 feet, 1,000 feet, and 600 feet respectively in the rivers Brahminee, Pattia, Byturnee, and Burrha. The practice on the Mahanuddee weir sluices had been hitherto, as stated by Mr. Buckley, to throw down the lower shutters by jerking the wrought-iron struts out of the cast-iron shoe in which the bottom of the strut rested, by blows from a heavy wooden lever. The shutter, 6 feet 4 inches wide, was supported by two struts. When therefore one strut was jumped out of position, the shutter was necessarily supported for a short time by only one strut. The water-pressure, therefore, gave the shutter, while thus unequally supported, an awkward twist, sufficient sometimes to fracture the iron sockets to which the shutter was hinged on the floor of the sluice opening. Although in the course of twelve years no fatal accident had occurred, and the shutters had often been thrown down with a pressure of $6\frac{3}{4}$ feet depth of water behind them, the process was plainly attended with some danger to the men manœuvring them. An improved form of strut was accordingly devised by Mr. G. H. Faulkner, the executive engineer in charge of the Cuttack workshop division, who constructed the shutters, by which the fall of the back shutter was effected instantaneously with safety and with a degree of facility which the former rather rude method of lowering it certainly did not possess. The strut, according to Mr. Faulkner's plan, was formed like the letter A, and was hinged, not by the upper end to the shutter, as on the old plan, but by the lower ends to an iron bracket bolted into the masonry floor. Near the top, and in the middle of the shutter, a large bracket with deep cheeks was bolted, and within it was attached a double-jointed lever. The head of the strut, when the shutter was up, rested against the shorter arm of the lever, as shown in Fig. 11, while the longer arm was secured to a snug in the bracket, from which it was released by a simple

trigger action. When the lever was released it flew up, and the Mr. Walker. pressure of the shutter immediately overturned the strut, causing it to revolve on its lower ends. The shutter fell with and over the

Fig. 11.



strut, which dropped into a recess in the floor. Various other modifications which experience proved to be necessary were made in the other parts of the shutters. The chains of the upper shutters, at first of only $\frac{3}{4}$ inch, were gradually increased to $1\frac{1}{8}$ inch, and in some cases three chains instead of two were given to each shutter. As this rendered the upper shutters rather sluggish in rising when they were released from the clutch bar, the boarding and stiffening battens were increased at the up-stream or free end of the shutters to give them more flotation. These improvements enabled him with confidence to recommend the construction of the weir across the river Pattia of shutters entirely, and the work had since been successfully carried out. The weir was about 900 feet in length, and the river had a rise of flood above low water of 22 feet. The sill or crest of the solid lower part of the weir was $3\frac{1}{2}$ feet above summer water-level. On this the double row of shutters on M. Thénard's principle had been erected, the upper shutters being raised when the depth of water passing over the sill was $7\frac{1}{2}$ to 8 feet in depth, and the lower shutters being capable of sustaining and of being lowered under a pressure of 10 feet

Mr. Walker. depth of water. The weir was divided longitudinally into bays of 42¾ feet by masonry piers 9 feet in thickness. This unusually large dimension was given to allow of the piers being carried up 10 feet above the highest floods, and to carry a foot-bridge for the convenience and security of the men working the shutters. Each bay contains six pair of up-stream and back shutters. This plan of keeping the body of the weir low and making the shutters practically continuous had been attended with excellent results; and although this form of weir was comparatively costly, it at all events prevented the accumulation of islands and shoals above the work.

So far as he knew this was the first work of the kind, on a large scale, in which shutters formed the entire weir; and he believed it would be the forerunner of similar works, so seriously was the shoaling above weir found to interfere with the efficiency of continuous stone weirs with high crests.

He could speak from personal experience of the practical efficiency of Mr. Fouracres' system of self-acting shutters, even in its present form. He was of opinion, however, that if it was to be used with a greater depth of water passing through the sluice vents than 7½ feet, the width of the shutters must be considerably reduced.

Mr. Williams. Mr. E. Leader Williams regretted that reference had been made to fixed weirs in the Papers under discussion. No new facts had been given on the subject, or any special works referred to; and yet strong assertions had been made that were not consistent with the experience of engineers, at least in this country. A barrier placed across a river for stopping, raising, or diverting the water, as a weir had once been defined to be, might be a dam only, and often was nothing else. It was not therefore surprising to find Mr. Vernon-Harcourt affirming that "the alteration of existing weirs would be indispensable in any scheme for mitigating floods, as the present weirs greatly impede the flow." No proof was given for such a sweeping statement. If true, it affected every river navigation in England, and reflected on Telford, Smeaton, Sir W. Cubitt, and other engineers who designed these works. Mr. Vernon-Harcourt was also equally positive as to oblique weirs, and he directly contradicted the result gained by the experience of those weirs on the Severn. It was not to be supposed that all existing weirs were perfect, or that improvements were not necessary, but it certainly was not the case that "the present weirs greatly impede the flow." This assertion was opposed to the Report of the Select Committee (H.L.) on Conservancy

Boards, viz.: "The evidence before the Committee points to the conclusion that weirs and dams, when constructed in a proper manner, are not necessarily prejudicial." This Report was the result of evidence given as to existing fixed weirs. Mr. Buckley's Paper also dealt with fixed weirs. He stated that "the first effect of the construction of a weir across a river is that the pool formed by it gradually silts up." If this was meant to apply to Indian rivers only, it should have been so stated. In that case it proves that the design of the weirs was faulty, or that other agencies were at work than those found in this country. Mr. Williams.

In Mr. Williams' experience on the rivers Severn, Weaver, and Irwell, he had never met with such a case, whether the weirs were provided with sluices or otherwise. On the contrary, he had known the weir pools, and the river above them, considerably deepened by the action of the weirs. Mr. James Walker was retained by the landowners to give evidence against the proposed erection of weirs in the Severn (1841). He said that "the shoals formed by the proposed weirs would be greater than those now existing. In fact, the bottom of the river would rise to the level of the top of the weirs." After inspecting the works when completed, his views were changed, and Mr. Walker had told him (1851) that in designing a main drain for the Middle Level drainage, he had profited by the success of the Severn works. As far as practicable, Mr. Walker made the drain without any fall, so as to hold a bed of water on which the first rise would take place. This put the main drain in the same position as a pounded river channel. This was Smeaton's practice, who in his Report on the Fossdyke Navigation and Drainage, 1782, advocated level deep drains, as against "that slow, lingering manner which is the consequence of shallow drains, containing no competent body of water in the bottom to be moved; for, let the body be however great, gravity, acting with equal force on every particle, the fall being the same, will give every particle an equal velocity, and consequently the whole."[1] A river in its primitive state was a succession of shallow fords and pools, more or less deep. The fords were natural weirs, and although of a bad form for the discharge of water, the pools above them were found to maintain their depth. In improving a river for navigation, these numerous fords were dredged out, and were replaced by a few weirs of nearly vertical section. If the work was properly designed and carried out, small floods would pass off with greater rapidity, and large floods would not be in-

[1] *Vide* Reports of the late John Smeaton, F.R.S., vol. i., p. 82.

Mr. Williams. creased in height. The pounds should be so arranged that no weir penned back on the land drains, and the weirs should be constructed so as to afford greater capacity for the discharge of flood waters than formerly existed in the same place. This was best accomplished by widening the river, and putting in an oblique weir. Increased length was thus made for the overflow, and the greater width of channel gave the current a clear run to the weir. The pool formed above it acted as a reservoir, and ensured a more even discharge, and if well proportioned it would not silt up, but would be kept clear from deposit by the action of freshes. Although in large floods the weir would be drowned, the increased area given to the river by widening, would allow of the floods having the same, or greater area for discharge over the site of the submerged weir. The effect of a flood coming into a weir pound was to set the whole body of water into rapid motion, however sluggish the stream might have been before. The result, as long as the weir was in action, was to pass off the flood with less head or rise. This was conclusively shown by the Severn works. By the Act of 1842, locks and weirs were constructed between Stourport and Worcester, but the opposition of the landowners postponed the erection of the weir near Tewkesbury, and compelled the adoption of dredging only. The result was to lower the low summer level of the river below the Diglis weir, near Worcester, nearly 3 feet, and it was not found possible to maintain a depth of 6 feet for navigation. In fact, the natural weirs had been dredged out, and nothing put in their place. Increasing the depth by embankments would only have diminished the waterway for floods, and another Act was obtained in 1853, authorising the construction of a weir and lock below Tewkesbury. This weir raised the level of the water at the foot of the Worcester weir, 16 miles higher up the river, 3 feet, the depth previously lost by dredging. Important tributaries joined the Severn between the two weirs, which accounted for the rise of freshes in the annexed Table not always being in relative proportion.

It would be seen that a fresh of 5 feet 6 inches in height, even when the rise due to the lower weir was added, was less than before. This proved that floods passed along a deep pound, and over well-designed weirs, with a greater velocity than along a natural channel, even after the shoals had been deepened. As soon as the rise commenced at the upper end of the pound, the increased head set the whole body of water into rapid motion, and the greatly increased hydraulic mean depth gained by pounding the water, facilitated the discharge. Fall was one element in the question

of velocity of moving water, but not the only one. It was well known that the tidal wave travelled faster as the channel deepened. Mr. Williams.

RISE of a FRESH ABOVE and BELOW DIGLIS WEIR, WORCESTER, BEFORE the CONSTRUCTION of the UPPER LODE WEIR, TEWKESBURY, as COMPARED with the RISE of a SIMILAR FRESH AFTER the COMPLETION of that WEIR.

Rise above Weir at Worcester.	Rise below Weir on Dredged River.	Rise below Weir on Dredged and Pounded River.	Total Rise, including Lift of Tewkesbury Weir.
Inches.	Feet. Inches.	Feet. Inches.	Feet. Inches.
3	1 11	0 5	3 5
5	2 3	0 9	3 9
6	3 3	1 1	4 1
8	4 6	2 0	5 0
10	5 6	2 5	5 5

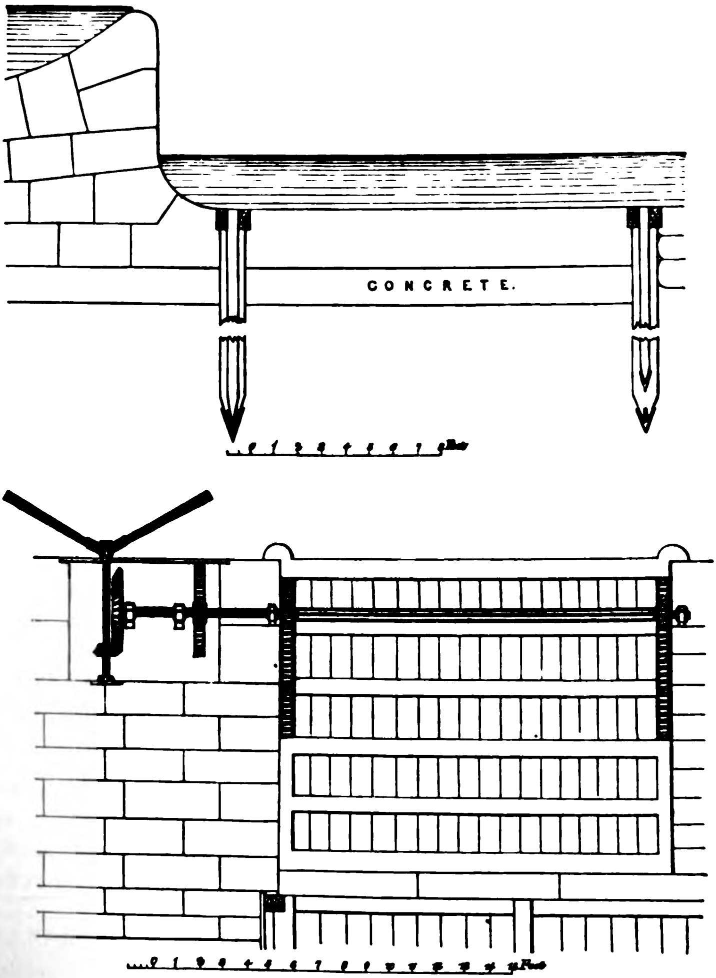
Admiral Beechey, in his notes of the survey of the Severn, stated, that the bore below Gloucester increased its velocity from 4 miles an hour to 10 miles, when the river was under the influence of freshes. As greater mean depth was so effective, even when the currents were running in opposite directions, the greater velocity of floods on pounded rivers could be easily understood. The irregularity of the sides of some rivers interfered with the discharge. If the banks were laid to a flat slope, and the channel made as uniform as possible, the landowners would gain in every way. Fixed weirs had many advantages. They were cheaper in construction and maintenance, and needed no supervision during floods. The water-way was always clear for the passage of ice and floating rubbish, and on the Severn the trade was passed over the weirs in floods, saving the delay caused by locking. The question of ice was important. On the river Weaver he constructed special weirs for the passing of ice, and steam-tugs were used to break it up. Weirs with a flat slope were in such cases objectionable. He had known ice accumulate on the slope, and much damage caused when the river rose after a thaw, by the stones being drawn out of the weir.

The weir at Winnington, near Northwich (Figs. 12 and 13, see next page,) had been reconstructed in 1859, and its length increased from 114 to 246 feet. He adopted a vertical section as far as possible, and the weir had cost nothing for maintenance since its completion. It was built of red sandstone, with a cap of Anglesey limestone in lengths of from 6 feet to 8 feet. The plan was segmental,

Mr. Williams. with a rise in the centre of 40 feet. The sluice, 16 feet wide, was at the end of the weir, and was easily worked by two men. This description of sluice was adapted to falls not exceeding 8 or 10 feet,

FIGS. 12 and 13.

WINNINGTON WEIR.



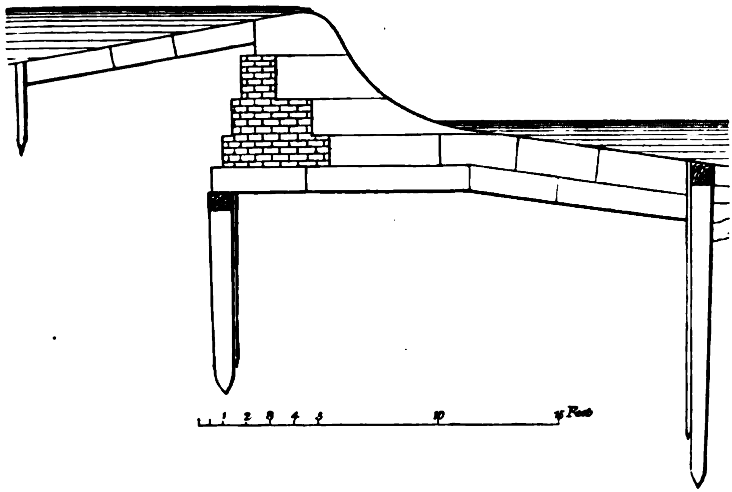
Elevation of Sluice.

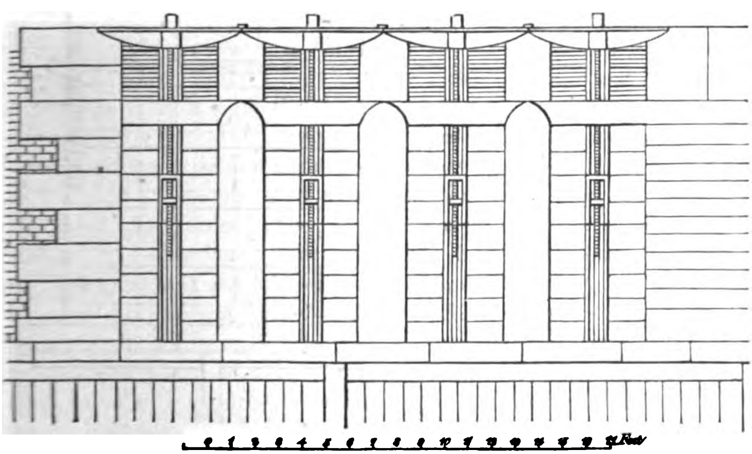
and up to 20 feet wide. Sluices at the ends of weirs were useful to lower the pounds for repairs, and if lifted early, materially assisted the passage of floods in small rivers.

Apart from the question of fixed weirs, the Papers gave much useful information; and as from local causes movable weirs might in some cases be advantageous, comparison could be drawn between the systems adopted by French engineers and sluices as gene- Mr. Williams.

Figs. 14 and 15.

Salterbford Weir.





Elevation of Sluices.

rally used in this country. The arrangements described were somewhat complicated, and liable to get out of order, and the variety in

Mr. Williams. the designs showed that no one had yet been found thoroughly effective. On the other hand, properly designed sluices were entirely reliable, and could be used with much less interruption to trade on the river. Any system that required the pound to be lowered below the navigable depth, after each flood, in order to reinstate the weir, was faulty. Floods were a serious cause of delay on river navigations, and this evil should not be increased by weirs that could not be closed without lowering a long reach of river.

In some instances a combination of sluices fixed on a low weir was best. Sluices that worked to the full depth of the river, where the fall was considerable, were expensive in construction, and needed very good foundations. No dogmatic rules could be safely adopted on any question affecting the treatment of rivers; but the engineer who fully investigated the conditions of each case, and then brought to bear upon it the result of matured experience, would have no difficulty in designing and executing the works required.

Saltersford weir (Figs. 14 and 15, see p. 147) was a good example of a fixed weir; it was designed by Telford. The small side sluices were those originally used on the Weaver Navigation.

Mr. Vernon-Harcourt. Mr. Vernon-Harcourt, in reply, said, in reference to some remarks by Mr. Buckley, that he had included M. Girard's system of raising a shutter weir by the application of hydraulic machinery, under the general head of movable shutter weirs, to which class it properly belonged, and had furnished a drawing showing the method of working it. He was glad that further particulars had been given of this ingenious system of raising a shutter against a head of water. Perhaps he had not given sufficient credit to the ingenuity of the idea, as he had been accustomed to see hydraulic machinery applied in so many ways at large docks. The weir at Brûlée island, to which he had referred, was the only one that had hitherto been erected; and, though perfectly successful, he understood, from inquiries he made when in France, that the system was too expensive to be likely to be adopted again. He thought that Mr. Buckley's question, as to how the peculiar working of the drum weir could be accounted for, would be answered best by the aid of an illustration. Suppose a water-supply pipe to be connected with a main, and pressure gauges put on at intervals along the pipe, and suppose that leaks occurred in the pipe in each of these intervals. The gauge nearest to the main would register the full pressure, but the next gauge, owing to the intervening leak, would indicate a less pressure, and the readings of each successive

Mr. Vernon-Harcourt.

gauge would be lower and lower, in consequence of loss of pressure due to the leaks and friction in the pipe. Precisely the same thing occurred in closing the drum weir when worked, as he had seen it, from one abutment alone. The water from the sluiceway entering the nearest drum, imparted the full pressure of the head of water to the lower paddle in the drum; but in lowering the paddle a certain amount of leakage took place at the bottom and sides of the paddle, and a certain amount of friction had to be overcome. Consequently the pressure of water entering the second drum was less, and it diminished in each successive drum, till at last, if the upper sluiceway was only partially opened, the transmitted pressure became too small to lower the lower paddle completely, and finally not enough to move it. The opening of the weir required a different explanation. When the weir was closed, and the lower paddles consequently were all vertical, they pressed against a projecting frame in the drum, which prevented leakage. The paddles being at rest, and leakage stopped, the pressure of the water in the up-stream compartments of the drums was hydrostatic, and equal throughout. To open the weir this pressure had to be reduced by lowering the upper sluice gate, and raising the lower sluice gate; these gates, being connected by a sort of see-saw arm, were moved simultaneously and through the same distance, one going up as the other went down. As soon as the pressure on the up-stream side of the lower paddles was reduced so as to be slightly less than the pressure of the stream on the upper paddles, all the paddles would seem to be free to revolve. The lower paddles, however, could not rise till some of the water had been forced out of the up-stream compartments of the drum; and this could only be done through the sluiceway in the abutment. Accordingly the paddle in the drum next the abutment, being nearest the outlet, had to exert less force than the others to force the water out of the up-stream compartment of its drum, and rose first. Having risen a certain amount, the pressure on the upper paddle, in its lowered position, was reduced, and the balance of pressures re-established. When the upper sluice gate was still further lowered, the pressure of water in the up-stream compartment of the drum was gradually reduced; and the lower paddles gradually and successively rose, forcing the water on their up-stream sides through the sluiceways in the abutment, till at last, when the sluice gates had been shifted sufficiently, the whole of the lower paddles were raised, and the weir completely opened. The reason, he thought, why the paddles did not rise or fall in absolutely regular order commencing from the abutment—a fact

Mr. Vernon-Harcourt.

he had himself noticed at Joinville—was that some revolved with less friction than others, and accordingly could be moved with a less pressure. As mentioned in his Paper, and referred to by Professor Unwin, sluiceways were made in both abutments of the more recent of these weirs to control more effectually the movements of the paddles; but this would necessitate the employment of two men, as there was no foot-bridge across the Joinville weir, and accordingly he, and he understood Mr. Buckley also, had seen it worked by one man from one side only of the weir. As the traffic on the largest French rivers, and through Paris, was made dependent on the works he had described, there appeared to him no occasion for the unwillingness expressed by Mr. Wells to trust the trade of the Weaver to similar works.

Two subjects had been dealt with in his Paper; one, fixed weirs, which had twice previously formed the subject of long discussions at the Institution; and the other, movable weirs, which had never been brought forward before. He accordingly had, as he thought, acted for the best in the interests of the Institution in dealing briefly with the old subject, and referring for further information to the Minutes of Proceedings, and in dwelling at length on the novel subject of movable weirs. He had no wish to treat fixed weirs with indifference, as suggested by Mr. Parkes, nor did he consider them obsolete; though M. de Lagrené in his valuable treatise,[1] stated that since the introduction of movable weirs in France fixed weirs had been abandoned.

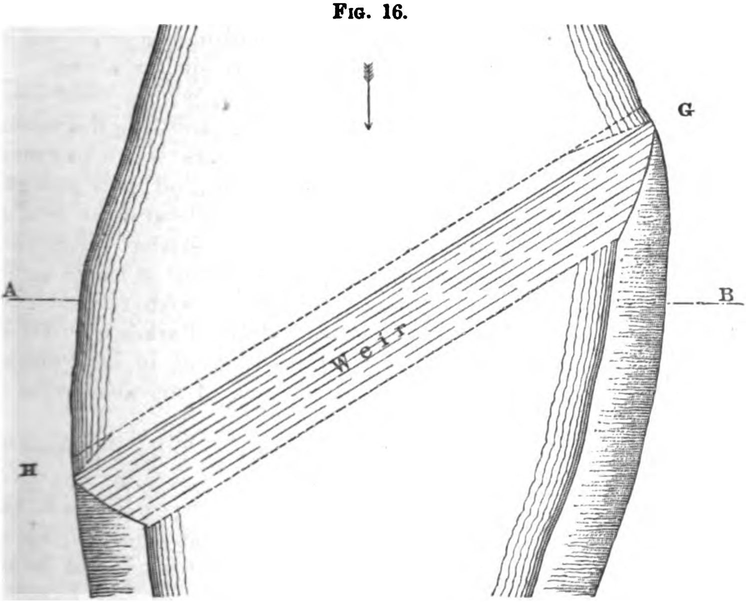
The subject of oblique weirs had been so fully discussed on previous occasions, that it had seemed unnecessary for him to do more than express his opinion on the subject, especially as he had imagined that it would be admitted, without question, by all engineers in the present day, that an obstruction placed in the channel of a river could not increase its discharge. As, however, two experienced engineers, Mr. Parkes and Mr. Redman, held opposite opinions to his, and as Mr. Parkes challenged him to prove his statement or to withdraw it, and was seconded in this by Mr. Redman, he had no option but to go further into the question. Mr. Parkes had stated that the system of solid weirs claimed to give a really better discharge for the floods than the unimproved river itself gave. This, in justice to the memory of Sir W. Cubitt it must be said, was not Sir W. Cubitt's view of the case. In the course of the discussion in 1846 Sir W. Cubitt said: "The bed of the Severn was very steep in the upper part, so that the flood

[1] *Vide* "Cours de Navigation Interieure." M. de Lagrené, vol. iii., p. 173.

Mr. Vernon-Harcourt.

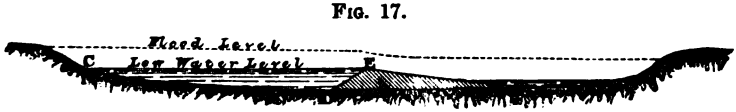
waters descended with great velocity; and if they were permitted to flow freely down without any weirs, they would flood the lower country much more rapidly than when the course was properly controlled by weirs; . . . that the object of the works was to place in the channel such obstructions to the course of the river as should retain a certain depth for navigation." [1] Sir W. Cubitt, however, considered that the only obstacle presented by an oblique weir to the flow of a river in flood time was, as repeated by Mr. Parkes, the cross section of the weir at right angles to the current, namely, the cross section along A B (Fig. 16), and marked by

Fig. 16.



the letters D E F in the section (Fig. 17). But if the weir was 10 feet high, and the flood waters flowing 10 feet above it, the

Fig. 17.



Section along A B.

channel at the weir, whether the weir was straight or oblique, would be reduced to half its depth at the weir, and would therefore

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. v., pp. 352 and 353.

Mr. Vernon-Harcourt.

require an additional head to force it through the diminished channel. Or, in other words, the water, C D E, above the weir and below its crest, would require to be raised to get over the weir, and this could only be effected by a rise of the level of the water above the weir. Moreover, the raising of the water over the weir would create a reaction on the bed, which would account for the scour above the weir, as mentioned by Mr. Parkes and Professor Unwin. Mr. Parkes' view as to the merit of oblique weirs in increasing the discharge, was brought up in the discussion on the Severn works in 1860, and condemned by Mr. Hawksley, who said, that the elevation of the weirs on the Trent had produced floods in its valley, and that "as he had heard it asserted, that works of this kind did not have the effect of elevating the surface of the water, against this doctrine he protested, both in a practical and in a scientific point of view." Mr. Hemans also stated "that a number of weirs erected on the Shannon had had the effect of raising the flood waters." [1]

In 1877 Sir John Hawkshaw recommended that the Grand Sluice at Boston should be enlarged to provide additional discharge for the flood waters of the Witham; and in 1878, that to prevent summer floods in the Upper Thames valley, weirs with high sills should be removed, and additional sluiceways provided, which sufficiently indicated his views on this subject. Mr. Leach, moreover, could not be a convert to Mr. Parkes' theory when he erected the draw door sluices across the very oblique weir at Teddington; nor Mr. W. Forsyth, who was about to erect similar sluices across the Shannon. Mr. Parkes, however, stated as a fact that the erection of solid weirs had improved the discharge of the Severn, and doubtless one fact was worth a great many opinions; and apparently his theory rested on this fact alone. He stated also that the oblique weirs were the only artificial works executed. That the weirs were not the only works was sufficiently clear from the following extract from Mr. Leader Williams' first Paper:—

"In the upper district, the channel of the Severn was intersected by numerous fords, composed of beds of red sandstone rock, marl, and gravel . . In this case, the remedy adopted was the removal of these fourteen natural dams, which, from their extent and consequent friction, seriously impeded the discharge of the flood waters, and by the substitution of four artificial weirs dividing this part of the river into four successive deep reaches, having a minimum depth of 6 feet, thus facilitating the navigation of the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xix., p. 540.

Mr. Vernon-Harcourt.

river, and the discharge of the flood waters."[1] Fourteen very broad natural weirs were removed, and only four artificial weirs were substituted; and in Mr. Leader Williams' second Paper he stated, that more than 1,000,000 cubic yards of material had been dredged from the bed of the river.[2] Mr. Parkes had omitted these important works entirely from his consideration, and had given all the credit due to them to the oblique weirs, which, as Sir W. Cubitt frankly stated, had been put up to retain the water for navigation, and to prevent the too free discharge of the improved river from flooding the land below. The scour observed was doubtless due to the improved state of the river channel, and to the action of the water on approaching the weir. It was satisfactory to find, on a careful review of all the actual facts, that no anomalous results had been produced by the erection of the weirs on the river Severn, and that the diminished rise in the flood waters, after the completion of the works, was fully accounted for by the removal of numerous shoals, and the increased sectional area of the channel. He considered that the advantage in the way of discharge that an oblique weir, such as G H, Fig. 17, possessed over a weir at right angles to the stream at A B, was equivalent to that which would be gained by a weir along A B, if the side bank was lowered from B to G, to the level of the crest of the weir.

The objections of Mr. Leader Williams to the observations on fixed weirs in his Paper appeared to be due to Mr. Williams regarding them with reference to the interests of navigation, whereas they had been made with a view to the prevention of floods. It could surely be no reflection on the works of former eminent engineers to suggest, for mitigating floods, modifications in weirs which had been established solely for navigation. He believed the Severn works, to which he had alluded, had been admirably contrived for improving the navigation without injuring the riparian proprietors; and that solid weirs were less objectionable in rivers with a considerable fall and high banks like the Severn, than in rivers with a small fall and low banks like the Thames. The judicious enlargement of the channel of the Severn had produced an improved discharge in spite of, not in consequence of, the erection of solid weirs. Engineers were, however, now called upon to increase the discharging capacities of rivers in flood time, and this might be promoted by substituting movable for fixed weirs.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. v., p. 340.
[2] *Ibid.*, vol. xix., p. 528.

Mr. Vernon-Harcourt.

He admitted that movable weirs would probably cost more than solid weirs; but he was of opinion that the advantage gained, of an unobstructed channel, would much more than compensate for the additional expense. He could not agree with Mr. Rawlinson that the influence of a solid weir did not extend a mile above it. He had found that removing obstacles from a channel had produced marked results for much longer distances. He believed that the great rise of water above the weir referred to by Mr. Rawlinson was due to the influence of the weir; and that the comparatively small rise over the crest of the weir was due to the removal of pressure by the fall of water over the weir, which enabled the water close to the weir to obtain a greater slope, and consequently an equal discharge with a less depth.

An opinion, expressed before some Committees, that a water channel would discharge more freely when full than when empty, had been referred to by Mr. Redman; but Mr. Vernon-Harcourt considered that this view had been successfully combated in a previous discussion on weirs, by the observation to the effect that, after the empty channel had been filled, the river would be in the same state as if it had been full at first, with the gain of having already discharged sufficient water from above to fill the channel; the empty channel acting, in fact, as a small storage reservoir. In reply to Sir Charles Hartley, and in reference to an observation of Mr. Manning, he might repeat, what he had previously mentioned, that M. Boulé's system of closing a movable frame weir with panels, though proposed, was not going to be adopted at Port-Villez; but that M. Caméré's system of hinged shutters, having been approved by M. de Lagrené, the engineer-in-chief of that portion of the Seine, had been authorised to be employed.

He considered Mr. Stoney had not quite understood the working of the French systems of weirs, when saying, that there was very little power in all except the needle weir of regulating the flow of water by degrees as the floods increased. The drum weir and the shutter weir, especially when the latter was provided with a foot-bridge, were capable of regulating the flow with perfect precision; and of course the same would hold good of the sliding panels, and hinged-shutter systems, applied to movable frames, which, being raised from below, worked in accordance with the principles advocated by Mr. Stoney. No obstruction was presented by the movable weirs when down, as Mr. Stoney imagined, as they were lowered into a recess below the sill; and in the Poses weir the whole of the weir would be lifted out of the water when opened. He presumed, however, that in Mr. Stoney's admirably contrived sluices, piers

would be necessary between each sluice gate, across a wide river, as in the ordinary draw-door weirs, which would present some impediment to the flow. Mr. Vernon-Harcourt.

He quite thought, with General Rundall, that no universal plan could be adopted for dealing with flood waters. Though it had been a matter of dispute whether the bed of the Po had been raised, or only the level of its floods, there was no question that the bed of the river Theiss had been raised,[1] and that the beds of some Japanese rivers were constantly rising.[2]

Probably, in some rivers, the removal of all silt would be difficult; but with the very efficient dredging machines now available, he did not regard it as such a hopeless task as Professors Hirsch and Gaudard appeared to consider it. He believed, that by enlarging a river channel, and removing all obstacles, the scour of the current would be increased, and thus, to some extent, aid in the improvement. He advocated this course in preference to the raising of banks; but if an adequate channel for the summer flood waters could not be provided at a reasonable cost, it might be supplemented by low banks formed of the dredged material. Embankments were necessary, where, as at Szegedin, a town, and, in the valley of the Po, extensive plains, were below the level of the rivers; but the erection of high embankments should if possible be avoided. They encouraged a false sense of security from floods, and rendered floods more disastrous when they occurred. If, moreover, the river bed was raised, as undoubtedly happened in several instances, the raising of the banks became eventually a more herculean task than the removal of silt from the channel.

As Mr. Forsyth and Mr. Manning were the only English engineers who had reported on the French systems of movable weirs, he had felt bound, in bringing the subject forward, to state frankly what he believed was the tenor of their reports. He was glad, however, to find that Mr. Forsyth, and more especially Mr. Manning, were not averse to the establishment of movable weirs on the river Shannon; and consequently that their opinions were more in accordance with his own as to the advantages that might be derived from the employment of movable weirs on rivers.

Mr. Buckley. Mr. BUCKLEY observed, in reply upon the discussion, that although it was perhaps in some respects to be regretted that the discussion on Mr. Vernon-Harcourt's Paper and his own had materially

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[1] *Vide* Rapports de la Commission des Ingénieurs Étrangers sur les Rivières Hongroises, 1879, pp. 25 *et* 109.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. lvi., p. 10.

Mr. Buckley. digressed from the chief subject of the Papers, namely, the movable portions of weirs, he himself could not regret that it had been so; for it must certainly be admitted, if the action of oblique weirs, of which so much had been said, could always be relied upon to be such as Mr. Parkes and Mr. Forsyth had stated that it was in certain cases, that in many cases the very expensive movable dams which had been erected could have been dispensed with. Mr. Howard Unwin, in speaking of Indian weirs, had said, "Without a movable dam, neither a navigable channel to the head lock, nor a sufficient supply of water to the canal, could be obtained;" and this had certainly been considered to be an axiom in India, where it almost invariably occurred that the river-bed was raised up to—or nearly up to—the crest of a weir within a few years after the weir was built. But Mr. Buckley thought that this axiom must be abandoned, and that Indian engineers must admit that, had they constructed weirs diagonally, they might never have required the very heavy, expensive, and troublesome under-sluices, or movable dams which had, in all cases, been placed in Indian weirs, and that they might have had deep pools of water, instead of shallow lagoons, covered with obstructive islands, above their weirs. But, at the same time, it must be remembered that, had the diagonal system been adopted in delta weirs in India, the cost of construction of the fixed portion must have been greatly increased; for not only would the length of the weirs have been greater, but it would have been imperative to greatly strengthen the up-stream faces and the wings to resist the scouring action of the parallel currents and the deepening of the channel above the weir, which, as he had pointed out in his previous remarks, were among the effects of diagonal weirs.

The superiority of the system of the Sone shutters had been challenged by Professor Hirsch. Now he wished it to be distinctly understood that, when he compared the Sone system with that of the various French systems, he did not maintain that it was in all, or even in most cases, superior to those systems for the conditions which they had to fulfil; he rather intended to compare the Indian system with the French ones under the conditions in which the Indian movable dam was placed. He had greatly admired the French movable dams, both in their design and in their construction; but he thought, although as Professor Hirsch had said, the Poirée dam was "capable of being provided with gear that allowed of its being opened with extreme rapidity," that the arrangement provided for doing this was a clumsy one, and inapplicable to Indian conditions. The Poirée dam could be

opened rapidly, by resting the upper ends of the needles against bars which could, at the will of the lock-keeper, be allowed to revolve horizontally on a vertical axis. When these bars were thus released, the needles would fall down stream, and the weir was opened. But it must, he thought, take much longer to do this than to release the let-go gear of the back shutter of the Sone weir, and the needles must often be broken in the fall, and frequently be carried away and lost. Professor Hirsch had also objected that the automatic action of the back shutters was sometimes dangerous; but the back shutter of the Sone weir, purposely to avoid this danger, had been fitted with the retaining chains mentioned in the Paper, so that the shutter could be set to act automatically or not, as was wished. Professor Hirsch, when he said that the "system of dams mentioned, which involved stone piers at intervals of only 20 feet, would be utterly impracticable for the majority of French weirs," had apparently omitted to notice the description given in the Paper of the improvements in the system which experience had dictated, by which those piers, certainly very objectionable in many cases, could be dispensed with. Mr. Buckley.

Reference had been made by Mr. Apjohn to the strain on the chains of the Midnapore shutters, which he seemed to think was as great as 111 tons. Mr. Buckley's calculations had been made from the following formula,[1] which had been promulgated by Captain Allan Cunningham, R.E., whose investigations on hydraulic questions were well known:—

b = breadth of shutter in feet.

$d = \left\{ \begin{matrix} \text{depth of shutter} \\ \text{,, stream} \end{matrix} \right\}$ in feet.

V = mid-surface velocity (over shutter when down) in feet per second.

w = weight of cubic foot of water = 62·5 lbs.

g = acceleration of gravity = 32·2.

P = total impulse of fluid on area $b\,d$ in lbs.

T = total sudden tension of whole set of chains in lbs.

α = inclination of chains to shutters when vertical, *i.e.* at instant when strained taut.

$$\text{Total tensile stress in lbs.} = \left(d + 4\frac{V^2}{g}\right) w\, b\, d \operatorname{cosec} \alpha.$$

He believed that this formula gave as approximate a result as

[1] *Vide* "Professional papers on Indian Engineering," second series, vol. iv., p. 28.

Mr. Buckley. could be expected in such a very intricate problem. He thought that the fact that the Mahanuddee shutters, which were larger than the Cossye ones, were now actually worked with 1¼-inch stud chains, showed that such a stress as 111 tons was much too great; no 1¼-inch chain would ever stand that, or half that strain. Mr. Apjohn had said that the Midnapore shutters had been lifted against a head of 7 feet 9 inches of water; but as he also stated that on that occasion half the chains had been broken, it would not be thought that the statement made in the Paper, that the greatest head against which any other shutter than the Sone shutter had been lifted was 6 feet 9 inches, was incorrect.

In speaking of the hydraulic brake shutters, Mr. Symons had referred to the probability of the outlet holes becoming blocked up with silt; this danger, which was not so much the danger of the holes themselves being blocked, as of the pipe being filled with silt through the holes, had been provided for by placing small blocks of india-rubber in such a position that, when the shutter was horizontal, the holes were entirely closed by the rubber, so that no silt could get into them.

It would be noticed that in the remarks which he had made previously he had described a system of movable dam (that of M. Girard), which was not altogether dissimilar to that of Mr. Fouracres. In Mr. Fouracres' system the shutter was lifted by the force of the stream against hydraulic presses, and was shut down by hand; in M. Girard's system, the shutter was shut down by the force of the stream, and was lifted against the stream by hydraulic pressure. It would be readily admitted that M. Girard's dam was by far the most complete, and he thought that, if some modification were adopted, M. Girard's system would be very applicable to Indian weirs. The angle at which the presses stood in the Brûlée Island weir would have to be altered in Indian weirs. It would probably be best to lay the presses horizontally on the floor of the under-sluices, and to have small supplementary presses fixed to work vertically beneath the shutters, to raise them the first few inches from the floor, until the connecting rods were at a sufficient angle to allow the horizontal presses to come into play. The turbines for the pumping machinery could be worked during the rains by the head of water, which would then always be available through the canal head sluices; in the dry season, if it were ever necessary to work the shutters, the difference of level between the water above and below the weir might be utilised. Indian engineers would probably fear that some accident to the pumping machinery would, in places where skilled labour was not readily

available for repairs, render the whole apparatus useless. To obviate this difficulty, it would be well to erect pumps which could be worked by hand if necessary. It would not be difficult to arrange that the working parts lying on the floor should be protected during the flood season by the shutters themselves. It was to be regretted that General Rundall had not referred to oblique weirs, as his great Indian experience would probably have suggested some valuable information on the point. He could not agree with General Rundall that a combination of the Sone system and Poirée's system would make a good movable dam for small rivers like those in England. He considered the Sone system directly applicable to great heads of water, and that it was too expensive to compare economically with some of the French systems, which were excellent for small heads. Mr. Buckley.

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27 January, 1880.

JAMES BRUNLEES, F.R.S.E., Vice-President, in the Chair.

The discussion upon the Papers on Weirs by Mr. Vernon-Harcourt and by Mr. Buckley occupied the evening.

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3 February, 1880.

WILLIAM HENRY BARLOW, F.R.S., President, in the Chair.

The following Associate Member has been transferred by the Council to the class of

Members—John Penn.

The following Candidates have been admitted by the Council as

Students.

William Nisbet Blair.
Allen Mason Brand.
Henry George Gilmore Dymoke.
James Robert Fawkner.
William Liddle.
William Marriott.
Richard St. George Moore.
William Page.
John Dann Smelt.
John Harrison Turner.

The following Candidates were balloted for and duly elected :—

Honorary Member.—John Tyndall, LL.D., F.R.S.

Members.

George Anderson.
John Champney Bothams.
Cuthbert Arthur Brereton.
Thomas William Miles.
Stair Agnew Stewart.
Lindsay Wood.

Associate Members.

Augustus William Harvey Bellingham, Stud. Inst. C.E.
Robert Charles Brebner, Stud. Inst. C.E.
Joseph George Chandler.
Charles William Freke Farewell, Stud. Inst. C.E.
John Rees George.
Charles Henry Holme, Stud. Inst. C.E.
Henry Burdon Hutchins, Stud. Inst. C.E.
George Jameson, Stud. Inst. C.E.
Robert Hill Julian.
John William Logan.
Edward Russell Morris.
William Weallens Shanks.
Charles Louis Sim.
George Henry Sykes, M.A.
John Clough Vaudrey, Stud. Inst. C.E.
Frederick Walsh.

Associates.

Samuel Buckle, *Capt.* R.E.
Robert Capper.
Clement Higgins, M.A.
John Orwell Phillips.

The discussion upon the Papers on Weirs by Mr. Vernon-Harcourt and by Mr. Buckley occupied the evening.

10 February, 1880.

WILLIAM HENRY BARLOW, F.R.S., President, in the Chair.

(*Paper No. 1691.*)

"Iron and Steel at Low Temperatures."

By John James Webster, Assoc. M. Inst. C.E.

From the earliest days of iron-bridge building, some forty years ago, to the present time, the opinion of engineers as to the condition of iron and steel at temperatures below the freezing point of water has been much divided. The general impression appears to be that both materials are to a certain extent affected when subjected to the action of frost, by becoming more crystalline in their structure, thus making them incapable of bearing the same strains they could sustain at a higher temperature. This impression has probably arisen from the fact of so many rails, tires, axles, chains, &c., having broken during severe winters. If, however, the returns issued by the Board of Trade be examined, it will be found that the majority of recorded fractures do not occur in winter; and even if they did, it has been often and justly held, that the fractures may have occurred not from the action of frost on the materials, but from other causes, such as the rigidity of the frozen road, restrained contraction of the materials, formation of ice in crevices, &c. On the other hand it must be remembered, that in those countries where the winters are longer and more severe than in Great Britain, no such records of fractures are kept, or possibly it might be found that they occurred more frequently in winter than in summer. Again, some of the fractures which are now recorded as having occurred at ordinary temperatures, may possibly have had their origin during a severe frost, and after the materials had withstood the working strain for some time, may finally have given way during perhaps one of the hottest months in the year, thus showing the impossibility of forming any opinion of value on what is merely circumstantial evidence.

Many eminent engineers gave a large amount of evidenc this subject before "the Commissioners appointed to inquire the Application of Iron to Railway Structures,"[1] and all wer opinion, that both wrought iron and cast iron were weaker at temperatures at or below the freezing point. The eviden this head was, however, nearly all founded on opinion, and from direct experiments. The principal experiments menti were those of the late Sir William Fairbairn, and of Mr. Br The latter, when giving evidence of the possible chang structure of iron from continued vibrations, said, "I should me that I have tried temperature also, freezing mixtures and wa and that the difference is decided; the iron in a cold state b shorter and shows more crystalline fracture than the same warmed a little; and I have no doubt, you might take 10 feet long and break it into ten pieces, and make them turn crystalline and fibrous according to the temperature little further on in his evidence he says, "I would just wi say, in reference to an answer which I gave to a former que that I believe that cast as well as wrought iron varies strength with the temperature."[2] No detail of the experi referred to were put in evidence, and the Author has not bee to find any record of them.

Since that time numerous experiments have been ma ascertain, if possible, the real condition of iron and steel a temperatures, but with no satisfactory results; for if the r were summarised, such a mass of contradictory evidence be found, that the question would appear almost as far off sol as ever.

Many of the experiments have been of the crudest form, need not be considered, although it is astonishing what st opinions have been formed and expressed by some engineers, stronger evidence for the foundation of their belief than per the breaking of a few bars of iron with a sledge hammer in wi or other trials equally rough and valueless. The most impor experiments on the subject, are those of the late Sir Will Fairbairn, M. Knut Styffe, and Mr. C. P. Sandberg, Assoc. Inst. C.E., and as the results obtained by them give import evidence on the question, it is proposed briefly to consider them

[1] *Vide* Report, 1849.
[2] *Vide* Report of the Commission, p. 358.

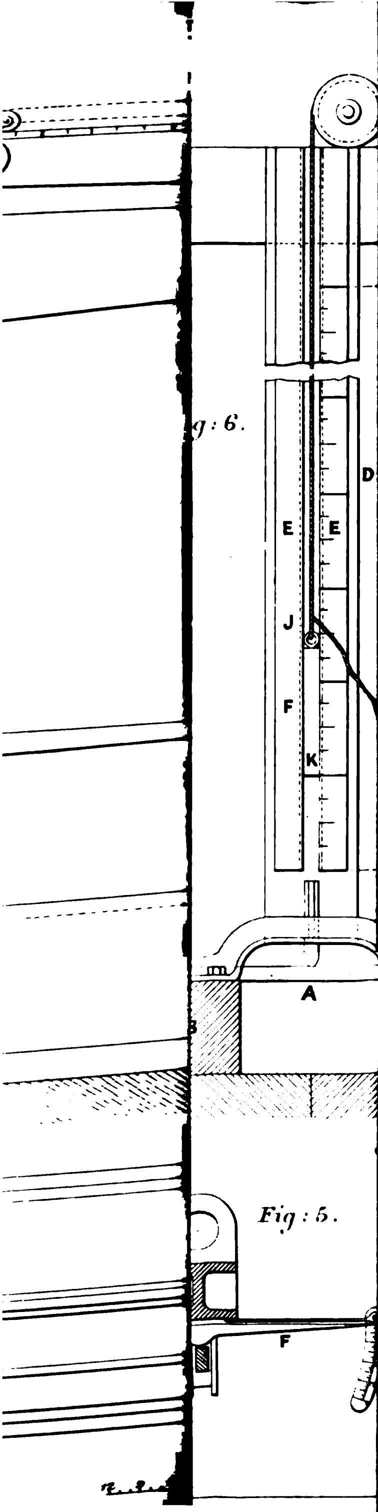

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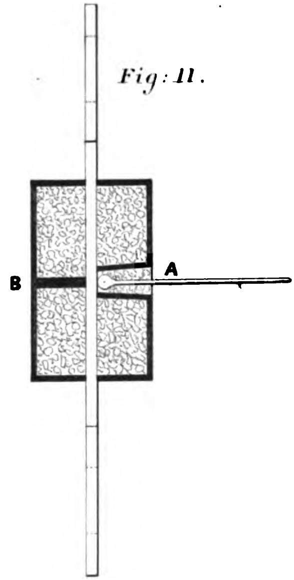
Fig : 5.



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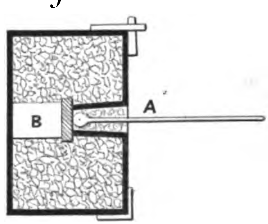

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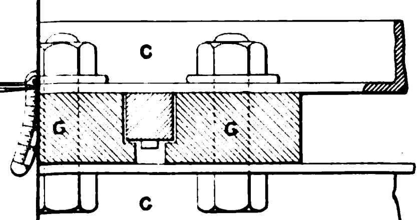

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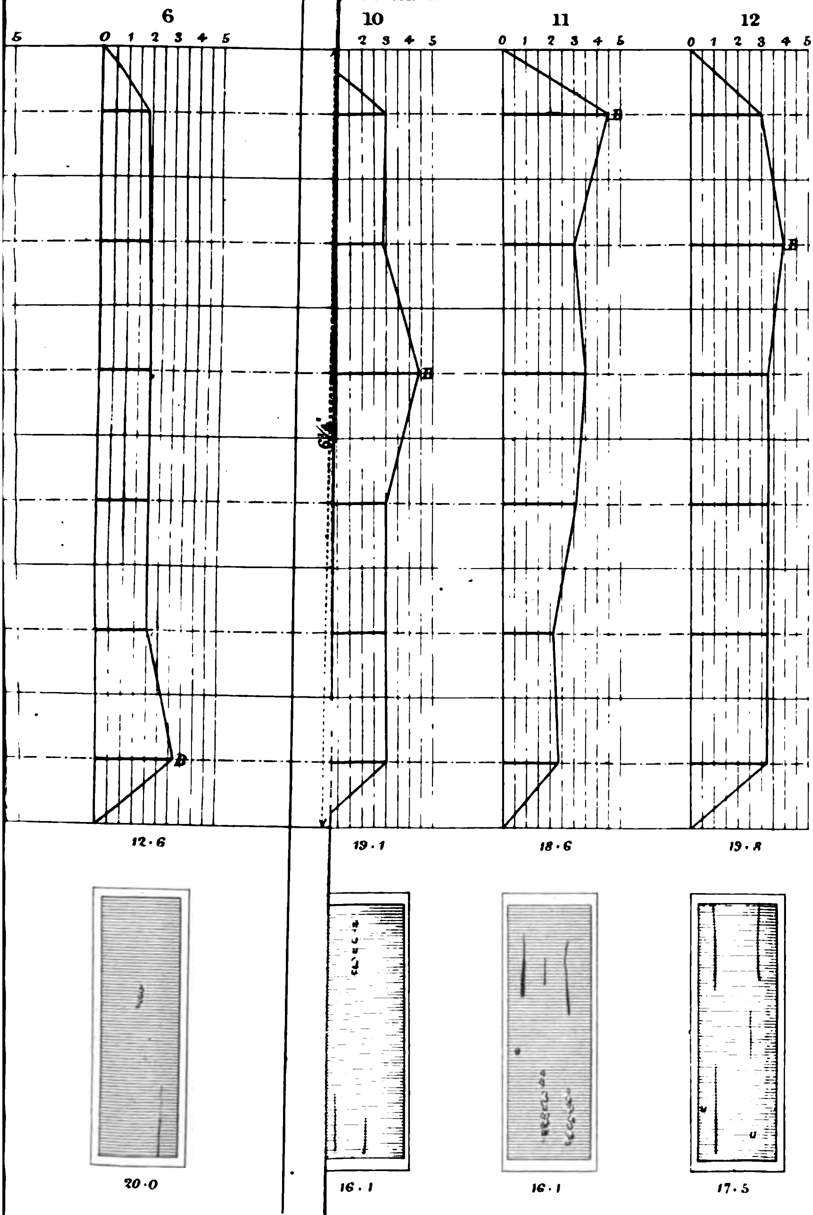
Fahrenheit.



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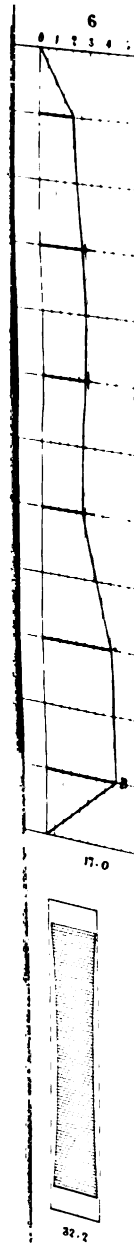

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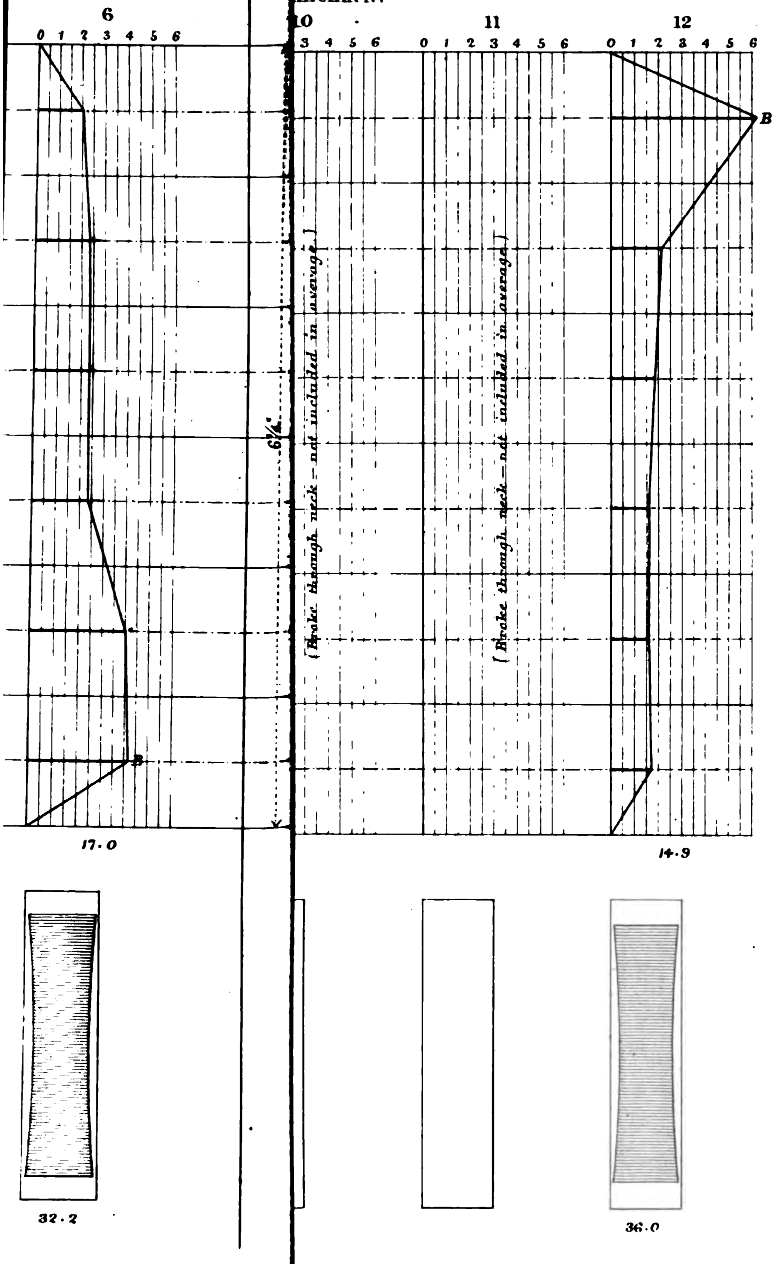

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EXPERIMENTS BY SIR WILLIAM FAIRBAIRN.

The first series of experiments by Sir William Fairbairn were those made upon cast iron only, and they formed part of his evidence before the Commissioners.[1] The experiments were made to ascertain the transverse strength of bars 1 inch square when placed on bearings 4 feet 6 inches apart; two bars being tested at a temperature of 26° Fahrenheit, four bars at 32°, two bars at 190°, and two bars at 600° Fahrenheit. As one half of the bars was of cold blast iron, and the other half of hot blast iron, the experiments were really reduced to a comparative test of three bars at the low temperatures, and one bar at the higher temperature.

The next trials, given in the same evidence, were made to ascertain the resistance of cast-iron bars to impact, and were under precisely the same conditions as the above, as far as regards the temperatures and number of bars tested. The summary of his evidence on these points was as follows:—"On the whole we may infer that cast iron of average quality, loses strength when heated beyond a mean temperature of 220°, and it becomes insecure at the freezing point, or under 32° Fahrenheit."

The next series of recorded experiments by Sir William Fairbairn are those in a paper read by him before the British Association in 1856.[2] In this instance, wrought-iron plates and bars were tested, and in the summary of results obtained at the different temperatures, one plate and one bar only are given as being tested at 0° Fahrenheit, and six plates and three bars at temperatures rising from 60° to 435° Fahrenheit. The test strips were broken horizontally in a single lever machine, having a scale pan at one end of the lever, but without any of the fine adjustments which are fitted to the machines of the present day. The results led him to believe "that iron bars or plates were not materially affected by cold." These experiments were evidently carried out more with the intention of ascertaining the strength of iron at high than at low temperatures, and although they were conducted and recorded as accurately as possible with the then existing apparatus, the Author is of opinion that the experiments on both cast and wrought iron were of far too limited a character to justify any definite conclusions being drawn as to the real condition of iron at low temperatures.

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[1] *Vide* "Report of the Commissioners appointed to inquire into the Application of Iron to Railway Structures," p. 321.

[2] "On the Tensile Strength of Wrought Iron at different Temperatures."—Report of the British Association. London, 1857. Page 405.

Experiments by M. Knut Styffe.

By far the most elaborate and carefully conducted experiments upon iron and steel at low temperatures are those by M. Knut Styffe, Director of the Royal Technological Institute at Stockholm. Of these a full account, with the results and conclusions arrived at, is published in a book which has been translated by Mr. C. P. Sandberg, Assoc. M. Inst. C.E.

The experiments were carried out in 1865, for the information of the Swedish Government Committee appointed to report upon the relative value of steel and iron in the manufacture of railway materials. The materials experimented on included a large number of samples of Swedish iron and steel, Krupp's steel, Lowmoor, Cleveland, and Welsh iron, and some bar iron from the Earl of Dudley's works. The principal object of M. Styffe's researches was to establish the exact limit of elasticity of each sample, considering this to be the true measure of its strength; but a large number of the tests were made to ascertain the tensile strength of iron and steel at very low temperatures. M. Styffe came to the following conclusions:—

(1.) "That the absolute strength of iron and steel is not diminished by cold, but that even at the lowest temperature which ever occurs in Sweden, it is at least as great as at the ordinary temperature (about 60° Fahr.)."

(2.) "That at temperatures between 212° and 392° Fahr., the absolute strength of steel is nearly the same as at the ordinary temperature; but in soft iron it is always greater."

(3.) "That neither in steel nor in iron is the extensibility less in severe cold than at the ordinary temperature; but that from 266° to 320° Fahr. it is generally diminished, not to any great extent, indeed, in steel, but considerably in iron."

(4.) "That the limit of elasticity in both steel and iron lies higher in severe cold; but that at about 284° Fahr. it is lower, at least in iron, than at the ordinary temperature."

(5.) "That the modulus of elasticity in both steel and iron is increased on reduction of temperature, and diminished on elevation of temperature; but that these variations never exceed 0·05 per cent. for a change of temperature of 1°·8 Fahr., and therefore such variations, at least for ordinary purposes, are of no special importance."[1]

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[1] *Vide* "Iron and Steel." By Knut Styffe. Translated by C. P. Sandberg, p. 111.

These results are contrary to generally received opinions, showing that, if anything, iron and steel are actually stronger at low temperatures. The experiments were conducted most carefully, and the results recorded very minutely, but one or two points are perhaps open to discussion. For instance, the sectional areas and extensions are given to $\frac{1}{10000}$ inch, and although an accurate measuring rod, regulated by fine micrometer screws, was used, yet, in direct measurements, no matter how delicate the apparatus, there is always a liability of errors, and it is only by such a device as that adopted by Professor Kennedy, in his testing apparatus at University College, that such measurements can be relied upon. The sections are stated to have been obtained with callipers, but even supposing they were vernier callipers, it seems doubtful if such minute measurements could be taken to four places of decimals.

The bars were about $\frac{1}{2}$ inch round or square, and were filed down to about $\frac{1}{8}$ inch square for a length of from 4 to 6 inches in the centre. It is to be regretted that the portion of the bar under the actual test was of so small a sectional area, as no doubt, when such small sections are used, errors are liable to occur; for supposing the bars to have been filed to such a nicety, if they were not perfectly homogeneous—a most probable condition—the percentage of error would be far greater than if the bars had been of larger section. This error would have been reduced had more samples of the same class of iron been tested; but the Tables show that although nine bars of iron and six bars of steel were tested at the low temperatures, in no case were more than two of the same quality of iron or steel experimented upon, the same number of bars being tested at the high temperatures to make the comparison.

The next most interesting series of experiments on this subject are those by Mr. C. P. Sandberg, which may be briefly described as follows.

Experiments by Mr. C. P. Sandberg.

Mr. Sandberg was of opinion that, although the experiments of M. Styffe might prove that iron and steel at low temperatures were not reduced in tensile strength, yet when subjected to sudden blows or shocks, they might possibly be affected by the action of severe frosts; and in order to ascertain this point, he made a large number of experiments which are fully described in the Appendix of his translation of M. Styffe's work.[1]

[1] *Vide* "Iron and Steel." By Knut Styffe. Translated by C. P. Sandberg, p. 154 *et seq.*

These experiments were made in Sweden in 1867, with seven iron rails from Aberdare, five rails from Le Creuzot, and two Belgian rails. The rails were all 21 feet long, and were broken by being placed on two granite blocks 4 feet apart, resting on a solid granite foundation, and allowing a ball weighing 9 cwt. to fall upon the rail between the points of support from varying heights. The two broken portions were afterwards tested in a similar manner; the tests were made at temperatures of 10°, 35°, and 84° Fahr.

From the results of his experiments Mr. Sandberg came to the following conclusions, viz.:—

(1.) "That for such iron as is usually employed for rails in the three principal rail-making countries (Wales, France, and Belgium), the breaking strain, as tested by sudden blows or shocks, is considerably influenced by cold; such iron exhibiting at 10° Fahr. only from one-third to one-fourth of the strength which it possesses at 84° Fahr."

(2.) "That the ductility and flexibility of such iron is also much affected by cold, rails broken at 10° Fahr. showing on an average a permanent deflection of less than 1 inch; whilst the other halves of the same rails, broken at 84° Fahr., showed a set of more than 4 inches before fracture."

(3.) "That at summer heat the strength of the Aberdare rails was 20 per cent. greater than that of the Creuzot rails; but that in winter the latter were 30 per cent. stronger than the former."

There can be no doubt of the accuracy of the results of these experiments. Is it equally certain that the decrease of strength recorded was entirely due to the action of the frost? The Author is of opinion that it is not, and for the following reasons:—

It must be noticed that nearly all the bars tested at the lower temperature were the 21-feet lengths, and those tested at the high temperature the short lengths; but if the bars had been all of the same length, different results would most probably have been obtained. The experiments made by Mr. Hodgkinson for the Royal Commissioners proved conclusively that in the case of a bar subjected to impact, the strength did not increase with the reduction of the distance between the points of support as in the case of a statical load; but that the strength actually decreased, the force evidently being taken up in bending the bar, and in overcoming its inertia. This conclusion is given as follows in the Report of the Commissioners:—[1]

[1] *Vide* "Report of the Commissioners appointed to inquire into the Application of Iron to Railway Structures," p. 105.

"The experiments in Tables I., II., III., IV., V. afford illustrations of some of the conclusions in the large generalisation of Dr. Young, deduced from neglecting the inertia of the beam (Nat. Phil., Lecture XIII.). 'The resilience of a prismatic beam, resisting a transverse impulse, follows a law very different from that which determines its strength, for it is simply proportional to the bulk or weight of the beam, whether it be shorter or longer, narrower or wider, shallower or deeper, solid or hollow. Thus, a beam 10 feet long will support but half the pressure without breaking, as a beam of the same breadth and depth only 5 feet in length will support; but it will bear the impulse of a double weight striking against it with a given velocity, and will require that a given body should fall from a double height in order to break it.'"

In Mr. Sandberg's experiments, the bearings were 4 feet apart in every instance, but the great overhang at each end, when a long rail was being broken, converted it into a continuous girder, thus virtually reducing this distance. Taking these things into consideration, it would appear that the differences observed in his results were to a great extent owing to the differences in the length of the rails.

It will thus be seen how fractures of rails in a permanent way are more likely to occur in severe winters than in the warmer months, the unyielding nature of the ground reducing the actual bearing of the rails to the conditions of a beam fixed at both ends, and having a span equal to the distance between the chairs, instead of having, as under ordinary circumstances, a much longer span, varying of course with the nature of the ground upon which they are laid.

Having briefly reviewed the results obtained, and the conclusions arrived at by different authorities, the Author ventures to submit a number of experiments he has made, as a contribution towards the solution of this question.

Experiments by the Author.

The materials tested in these experiments were wrought iron, cast iron, Bessemer steel, and best cast steel, as well as malleable cast iron, now extensively used for pitch chains, double links of dredgers, and other important purposes where wrought iron and steel were formerly employed.

As the results are intended merely to show the comparative strength of the materials when at ordinary temperatures, and

when under the action of severe frost, the numbers recorded must not be taken to represent the actual strength of any particular class of iron or steel; for the quality of the material was not of so much importance in the experiments as the fact of having all the bars in one set as nearly alike in every way as possible, although in many instances high results were obtained. In the first experiments the comparative tensile strengths of wrought iron, malleable cast iron, and Bessemer steel, were observed when at ordinary and at low temperatures, twelve bars of each being tested, six each at 50°, and six each at 5° Fahrenheit, the latter temperature being considered a fair representation of the severest frost likely to be experienced in this country.

The next experiments were made to ascertain the comparative transverse strength of twelve bars of cast iron, six being tested at 50°, and six at 5° Fahrenheit. Cast iron was the only material experimented upon for transverse strains, as it is almost impossible to test wrought iron or steel in this manner, owing to the great deflection of the bars before fracture; it is only in the common material that fracture will take place.

The succeeding experiments were with a view to observe the comparative effects of impact on bars of wrought iron, malleable cast iron, ordinary cast iron, and cast steel, twelve bars of each material being tested, six of each at 50°, and six of each at 5° Fahrenheit.

In all cases, the greatest care was taken to obtain each set as nearly alike as possible. The samples of wrought iron or of steel bars in each set were cut from the same bar, or two bars, rolled at the same time. When the samples were taken from two bars, to reduce any error which might possibly arise from one bar not being exactly the same as the other, three samples of each were tested at the low temperature, and three of each at the ordinary temperature.

The cast-iron test bars were all run from the same ladle, a large one being used for the purpose, that there might be an excess of metal after the operation of casting. The malleable samples were cast together, and annealed in the same oven.

All the bars tested at the low temperature were buried in snow for two or three days. Previous to being tested they were covered for about three hours with a freezing mixture of snow and salt, and were then taken direct from this mixture to the machine. While the test was being made they were kept surrounded with the mixture by being placed in a specially constructed box (Plate 7, Figs. 10 and 11).

Description of the Testing Apparatus.

The apparatus employed for determining the tensile and transverse strains of the different samples, was the testing machine[1] belonging to the Hull Dock Company, kindly placed at the Author's disposal by the courtesy of their Engineer, Mr. R. A. Marillier, M. Inst. C.E.

This machine consists of a series of compound levers, the straining power being applied by a small hydraulic pump. The general arrangement of the apparatus is shown on Plate 7, Fig. 1 being the side elevation, Fig. 2 the plan, and Fig. 3 the end elevation. H is the hand-pump which forces oil from the tank B into the cylinder C, acting on the top side of the piston, fitted with cup-leathers, and having a jaw forged on the piston-rod head, through which passes the pin D. The test bar E is held at the bottom by this pin, another pin F passing through the bar at the top, and connecting it to the two links G, which are hung on knife-edges fixed to the lever H, coupled by the links J to the top lever K. To this lever is hung the rod L, on which are placed the weights M, for ascertaining the test loads; the total leverage being 160 to 1. The top edge of the lever K is graduated up to 1 ton, and is fitted with a riding weight N, which is moved along by a cord passing over the fixed pulley O, and a small hand-wheel and pulley P. The weight of the levers is counterbalanced by the weights Q, and as all the connections are made by knife-edges, the friction is reduced to a minimum, a trifling weight being sufficient to turn the balance. A spiral spring below the piston forces it back into position after a bar is broken. This plan works satisfactorily, the only disadvantage being the increase of pressure in the cylinder, necessary to compress the spring, which varies with the extension of the test bar.

When tests are made with transverse strains, the cast-iron crosshead A, Figs. 4 and 5, is suspended from the lever H, the test bar B being placed on the knife-edges C; a clip D, with an internal knife-edge, rests on the centre of the bar, and is attached to the crosshead of the piston by the pin D, the pressure being then applied by the hand-pump as before. A small stud E, having its end filed to a knife-edge, is screwed into the crosshead A; and against this, and on the top edge of the test bars rests a light rod E, used as an indicator of the deflection; the real amount of this being multiplied

[1] The testing machine was constructed by Messrs. Bell, Lightfoot and Co., Walker Engine Works, Newcastle-upon-Tyne.

ten times, and read off on the graduated quadrant G, which is set at zero at the commencement of each test.

In making the tests with transverse strains, the riding weight was used to ascertain the loads up to 1 ton, and, if the bar did not break, was brought back to zero, and a weight representing 1 ton placed on the rod L, the riding weight being then used again up to the breaking point. The deflections were not self-registering, but were carefully noted as the loads were increased.

The apparatus used for determining the effects of temperature on bars, when subjected to impact, is shown in Plate 7, Figs. 6, 7, and 8. The bar to be tested, A, was placed upon two heavy cast-iron blocks B, kept in position by means of two angle-irons C, 4 inches apart, with distance-blocks between. On the bottom edge of the back angle-iron rested a 2-inch plank D, 18 feet long, by 12 inches wide, bolted to the angle-iron at the bottom, and to a cross beam of the building at the top. To this plank were fixed guides E, for the falling weight F to run between. Between the angle-irons C were bolted the distance-blocks G, shown to an enlarged scale in Fig. 9; between these again was placed a steel dolly 2 inches square, having an edge the width of the bar, and rounded to a radius of ½ inch; the dolly rested on the top of the test bar, the force of the falling weight being transmitted through it. To the front of the dolly was screwed a piece of hard wood, a space being left in the distance-blocks for it to work freely without touching the blocks or the angle-iron, and to this wood was fixed a strip of paper, a fresh piece being used for each test bar, and on it was carefully marked the permanent set after each successive blow. The falling weight was a piece of 3-inch-square iron, weighing 40 lbs.; it was lifted by a rope passing over a pulley H, and released at any height, by pulling a light cord attached to a simple disengaging hook J. The guides E were marked every 6 inches up to 15 feet, which was the limit of the fall, a small pointer K being fastened to the falling weight. A record of the height of each blow was kept, and the deflections read off the slip of paper were placed opposite to the corresponding fall, as shown in Tables V., VI., VII., and VIII.

When the bars were tested at low temperatures, they were taken from the freezing mixture in which they had been lying for three hours, and placed in position in a wooden box fitted between the iron blocks, the box being filled with a freezing mixture of snow and salt. The bar was kept covered during the whole time the test was being made. At the back of this box a small recess was fitted, A in Fig. 10 and 11, and arranged so as to press against the test bar,

being kept in position by a stop B, fixed on the other side; thus a portion of the bar was kept dry, and the recess free from the action of the mixture in the box. Into this recess was inserted the bulb of a thermometer touching the bar, and packed behind with cotton wool to exclude the external atmosphere. By these means a near approximation to the temperature of the bar was obtained.[1]

Although the freezing mixture was at zero, the temperature of the test bar was found in every case to be about 5° Fahrenheit, the difference of the two temperatures being due no doubt to conduction through the connections of the bar with the testing machine.

Experiments on Wrought-Iron Bars subjected to Tensile Strains.

The first experiments were made with twelve flat bars, six of them being originally 6 inches broad by ½ inch thick, and the others 4½ inches by ½ inch. They were rolled from the same pile, but to prevent any error arising from the difference of the two sections, three bars of each were tested at the low temperature, and three of each at the ordinary temperature. After the holes for the coupling pins had been bored, great care being taken that a line joining the two centres passed exactly through the centre of each bar, they were placed upon a mandrel, and all shaped together to a width of 1½ inch for a length of 6½ inches in the centre of the bar, a uniformity of the sections being thus ensured. Although pins were used for attaching the test bars to the machine, the plan of using serrated steel wedges or "dogs" is far preferable; for by that means a large amount of skilled labour is dispensed with in preparing the test bars, and there is not the same chance of errors arising from the direction of the tensile strain not passing through the centre line of each bar. After leaving the shaping machine, each bar was carefully examined and numbered; and on the centre line, which was marked with a fine scriber, two centre punch dots

[1] The Author originally intended to have observed the temperature of the test bars by a thermopile and galvanometer, one cone of the thermopile being placed in the recess next the exposed portion of the bar, and the other cone next a Leslie's cube; the difference of the temperatures being observed by the position of the reflected light of the galvanometer; but as he was disappointed in not having the apparatus completed in time for the experiments, he was compelled to use the thermometer. Although this apparatus would have been more sensitive to the variations in temperature, the recorded temperatures may be considered sufficiently accurate for the object of the present experiments. The thermometer was allowed to remain next the bar for about twenty minutes before the observations were taken, the bar being covered the whole of the time with the freezing mixture.—J. J. W.

were made at a distance of $6\frac{1}{4}$ inches apart, this length being the one taken to ascertain the ultimate extension. The distance adopted by various authorities is generally either 6, 8, or 10 inches, but the $6\frac{1}{4}$-inch gauge is a most convenient one, for by adopting it the percentage of elongation can be read off at once, every $\frac{1}{16}$ inch being equivalent to 1 per cent.[1]

As it was intended to observe, in addition to the ultimate extension, the amount which took place at different portions of the test bar, the distance of $6\frac{1}{4}$ inches was divided into six equal parts, accurately set out and marked with a centre punch; and as there was a possibility of the bar breaking outside either of the two end marks, a length equal to one of the divisions was marked beyond them.

The wrought-iron test bars were cut from flat bars made from faggoted scrap, and manufactured by the Hull Forge Company.

The malleable cast-iron test bars were cast by Messrs. Andrew Handyside and Company, Derby, from a pattern made to the required shape, the width in the centre being $\frac{1}{8}$ inch larger than the finished size, to enable them to be all shaped exactly to the section, after which they were set out and marked as before. The net sectional area of the bars was 0·75 inch.

The steel bars for the tensile tests were of Bessemer steel, manufactured by Messrs. Brown, Bailey, and Dixon, the test strips being cut from a bar $4\frac{1}{2}$ inches wide by $\frac{3}{8}$ inch thick, shaped, and set out as before, the net sectional area being 0·62 inch.

The results of the experiments with tensile strains are shown in Tables I., II., and III., in which are recorded the breaking strain per square inch of the original section, the percentage of extension, and the reduction of area at the fracture. The extension of the bars between the several points marked in their length is shown on Plates 8 and 9, where the thick horizontal lines from the centre of each of the six divisions represent the percentage of extension of the bars at those points, and can be read off by the vertical lines, which are drawn to a scale of $\frac{1}{8}$ inch to 1 per cent. The total percentage of extension is given at the bottom of each diagram, underneath which is shown the original section of the bar, with the reduced section inside, shaded to show also the nature of

[1] It would be far better, and would simplify matters considerably, if engineers would adopt some standard length from which to measure the amount of extension. Comparisons of results of different experiments could then be correctly made, whereas at present, the specified extension of any material is an ambiguous quantity, depending upon the length adopted, which, in many published tables of results, and in many specifications, is never mentioned.—J. J. W.

the iron at the fracture. The malleable iron castings are not represented by similar diagrams, for the total extension of the bar is so very small that the amount between each of the six divisions would be hardly perceptible.

It is the general opinion that, when a bar is tested, the extension along its length is uniform, except at that portion where the fracture takes place; that is to say, all the horizontal lines, except the one at the fracture, would be equal. The result of these experiments, however, shows that such is not the case, the irregularities in some instances, especially those for wrought iron, being conspicuous. This is important, as it raises the question of the value of the reduction of area as a measure of the ductility of the material; for it is possible to have a small reduction of area, with a large permanent extension, the latter condition being, in the Author's opinion, the best indication of the quality of ductility. The breaking strain is also occasionally expressed in terms of the reduced area of the fracture; but this can hardly be of much value, for the extension or reduction of area and the breaking strain represent two distinct qualities of the material, and one cannot be well expressed in terms of the other. Of two bars, one bar might possibly have a high breaking strain with a small reduction of area, and the other a low breaking strain with a proportionally large reduction of area; and if the above plan were adopted, the results obtained would have the same numerical value. Again, it is possible, and probable, in a bar of very ductile material, that before it actually breaks the strain is reduced; that is to say, the real strain required at last to part the bars is less than that applied before the ultimate extension takes place; and as this strain cannot be easily measured, owing to the suddenness of the change, it shows clearly that the breaking weight recorded is the amount required to fracture the bar of a certain original section; and should this amount be expressed in terms of the fractured area no real value can be attached to it.

Experiments on Cast-Iron Bars subjected to Transverse Strains.

Owing to almost the impossibility of breaking bars of wrought iron or steel with a transverse strain, on account of the great deflection which takes place before fracture, these experiments were limited to sample bars of cast iron. Twelve bars were experimented upon, six at 50°, and six at 5° Fahrenheit. Each bar was 3 feet 6 inches long, by 2 inches deep, 1 inch wide, and rested on its edge on supports 3 feet apart, in the crosshead shown in Plate 7,

Figs. 4 and 5. When the bars were tested at the lower temperature they were covered with snow for three days, and for three hours previous to the test with the freezing mixture, with which they were also covered during the test, in a long trough fitting up to the crosshead, the front being hinged to enable the bar to be withdrawn, and another inserted. The results of these experiments are recorded in Table IV., where the breaking strain of each bar is given in cwts., and the deflection before fracture in inches.

Experiments on Bars subjected to Impact.

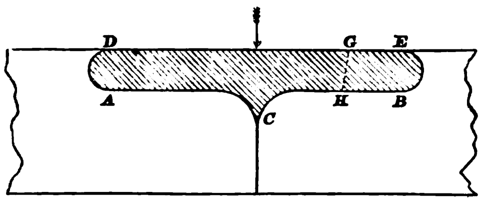
The materials used in these experiments were wrought iron, best tool steel, cast iron, and malleable cast iron; twelve bars of each material being tested, six of each at 50°, and six of each at 5° Fahrenheit. Those tested at the lower temperature were under exactly similar conditions to those which were subjected to tensile and transverse strains, as already described.

In testing the wrought-iron bars, the same difficulty was experienced with the great deflection as occurred when transverse strains were applied. Bars 1½ inch square, resting on supports 18 inches apart, could not be broken with a falling weight of 40 lbs., but were doubled up to an angle less than a right angle, and still showed no signs of fracture. Bars 1 inch square, resting on supports 9 inches apart, were then tried, with similar results; and it was not until iron was adopted of a smaller section, of a common quality, and with reduced bearings, that satisfactory results could be obtained. The twelve bars finally tested were of common iron, $\frac{7}{8}$ inch square, resting on supports 6 inches apart. The results of these experiments are recorded in Table VI., where the height of fall of a 40-lb. weight and the permanent deflection at each successive blow are given. The height from which the weight fell when the bar broke is not given, for in most cases, although this height was above the last recorded one, a fall of a few feet only would have sufficed to break the bar, and it may be fairly assumed that it was the previous blow which destroyed it.

The steel bars tested by impact were of best cast tool steel, 1 inch square, and were placed upon supports 18 inches apart. The samples were all cut from two bars rolled at the same time, and although it might be supposed that they were practically alike, the wide range of the results is very marked, the height of fall varying from 6 feet to 14 feet. The fracture of these bars was most curious, for in every instance, both at the ordinary temperature, and at the lower temperature, it took the form shown in

Fig. 1, the shaded portion coming away from the top side, and flying a considerable distance. These pieces were not always of the same size, and occasionally were broken across the part shown

Fig. 1.



by the dotted line at G H, but they were all of the same shape, and possessed the same peculiarities. The ends at D and E were rounded, both as shown in elevation in Fig. 1, and in plan in

Fig. 2.

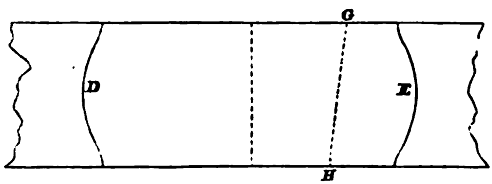


Fig. 2, the ends of the bar being concave to correspond, and the loose piece then finished off with a sharp knife-edge at C.

The under side of this piece, at the points A and B, was quite smooth, as if there had been friction, and the probability is that, under the succession of blows delivered on the top of the bar, it was drawn out, and as the portion of the bar above its neutral axis was in compression from the deflection, one portion was made to slide over the other, and thus the smooth surfaces at A and B were formed, the curves D A C, or E B C, evidently representing the neutral line of the two opposite forces. The bars at the lower temperature were prepared and tested under exactly the same conditions as those previously described. The results of these experiments are recorded in Table VII., where the height of fall and permanent deflection at each blow are given.

The malleable cast-iron bars tested by impact were 3 feet 6 inches long, by 1½ inch deep, by 1 inch wide, and were originally intended to have been broken with a transverse strain; but the deflection was again found to be so great that it was impossible to do so with the machine, the stroke of the piston not being long

enough. The bars were placed upon supports 1 foot 6 inches apart, and were tested in the same manner, and under the same conditions as the other bars, six being at 50°, and six at 5° Fahrenheit. The falling weight was 40 lbs. The results of these experiments are recorded in Table VIII.

The ordinary cast-iron bars tested by impact were 10 inches long, by 2 inches deep, by 1 inch wide, and rested on their edges upon supports 6 inches apart; the falling weight being 10 lbs. only, instead of 40 lbs., as in all the other experiments. The same number of bars was tested as before, and under similar conditions, the results being recorded in Table V.

Summary of Results.

A summary is given in Table IX., where the average of each set of experiments is tabulated.

Upon examination, the results obtained by submitting the bars of wrought iron and Bessemer steel to a tensile strain will be found to a great extent to agree with those by M. Styffe. The figures show clearly that severe cold does not affect the tensile strength of the materials, but that it increases the ductility of each of them.

When, however, cast-iron bars are submitted to a transverse strain, the results show that both their strength and flexibility are considerably affected by the action of severe cold; and when all the four metals, wrought iron, cast iron, steel and malleable cast iron, are subjected to the force of impact, the same result is observed in each, viz., that at a low temperature it requires either a lower fall or a less weight to break them, and their flexibility is considerably diminished. This result is the one anticipated by Mr. Sandberg, and although his opinion is to some extent confirmed by the present experiments, the differences observed in his experiments were far greater, perhaps for the reasons already explained.

The results of the experiments may be summed up as follows, viz.:—

1. When bars of wrought iron or of steel are submitted to a tensile strain and broken, their strength is not affected by severe cold (5° Fahrenheit), but their ductility is increased, about 1 per cent. in iron and 3 per cent. in steel.[1]

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[1] As far as can be judged from the small number of malleable cast-iron bars which fairly broke when at the low temperature, it would appear that the tensile strength of the material is not influenced by the action of severe frost, but that its ductility is decreased.—J. J. W.

2. When bars of cast iron are submitted to a transverse strain at a low temperature, their strength is diminished about 3 per cent. and their flexibility about 16 per cent.

3. When bars of wrought iron, malleable cast iron, steel, and ordinary cast iron, are subjected to a force of impact at a temperature of 5° Fahrenheit, the force required to break them, and the extent of their flexibility, are reduced as follows, viz.:—

	Reduction of force of Impact.	Reduction of Flexibility.
Wrought iron . . .	about 3 per cent.	about 18 per cent.
Steel (best cast tool) .	„ 1 „	„ 17 „
Malleable cast iron . .	„ 4½ „	„ 15 „
Cast iron	„ 21 „	not taken.

It will be noticed from the Tables that, when the malleable iron castings were tested with a tensile strain at the low temperature, four out of the six bars broke through the eye. This unfortunately interfered with a fair average being taken, but on the other hand, it strengthens the opinion that the material is influenced by the action of severe cold, for the sectional area of the bars through the eye was nearly twice that of the centre, and as in most cases the metal was perfectly clean at the fracture, the bar was evidently not broken by a direct tensile strain, but by some indirect action. This is probably accounted for by the fact of the hole for the pin being bored out slightly in excess of the diameter of the pin, when it would really only bear at one point at the top, thus causing the sides of the eye to be subjected to a transverse strain; and as the experiments tend to show that malleable cast iron will bear a less strain when under the action of severe cold, these fractures probably took place from this cause.

It will also be noticed that three of the steel bars broke at the low temperature through the neck, but this was owing to the tool in the shaping machine unfortunately cutting a nick in the three bars about an inch above the straight length, when they all broke away from this point, although the section was greatly in excess of that at the centre.

It is difficult to reconcile the results of the experiments on impact with those with a tensile strain; one appears to contradict the other. It must, however, be remembered that the conditions under which the bars were broken at the low temperature were not identical in the two cases. When the bars were being broken by impact, it may be fairly assumed, that their temperature was constant; but when they were broken by a tensile strain, it certainly was not so, for on approaching the breaking point the

temperature of the bars near the point of rupture increased considerably; instead of being at 5° Fahrenheit as at the commencement, it was much higher, notwithstanding the action of the freezing mixture. This rise of temperature is very sudden, and would probably only affect the ultimate breaking strain, and not the extension, which most likely would have taken place before the rise commenced; yet it is hard to conceive why the material should extend more in the cold, unless it be that the evident contraction or altered position of the particles tends in some way to increase its facility for being drawn.

The question now arises, which of the results is to be taken as indicating the real condition of iron and steel at the low temperature, those obtained from the experiments with tensile strains, or those obtained from the experiments by impact? As both materials, when manufactured into rails, tires, axles, chains, &c., are, when in use, continually subjected to sudden shocks or blows, and as there appears to be a doubt about the correctness of the results obtained by tensile strains on account of the great heat evolved before fracture raising the temperature of the bars above freezing point, the Author is of opinion that the conditions under which the tests with the falling weight were made, approached nearest to those of the material when in use; and the results so obtained should fairly represent the structural condition of the material when tested.

Although these results show that both wrought iron and steel are influenced by severe frosts, the reduction of their strength and ductility is so small, that in designing any new structures or machines it may be safely neglected. Great care should, however, be taken to prevent them from being subjected to more shocks and blows than necessary, and the examination of rolling stock and permanent way should be made frequently during frosty weather.

The results obtained with cast-iron bars show the state of affairs to be much more serious, and consequently every precaution should be taken to protect all cast-iron work subjected to transverse strains, as in girders, long columns, gearing, &c., from the action of frost; and should this be not practicable, the working loads ought to be reduced at least 25 per cent., notwithstanding the large factor of safety generally adopted in the original design.

The Paper is accompanied by several drawings, from which Plates 7, 8 and 9, have been prepared.

[APPENDIX.

APPENDIX.

TABLE I.—EFFECTS of TEMPERATURE on the TENSILE STRENGTH of WROUGHT IRON.

Number of Test.	Description of Material.	Makers' Name.	Original Sectional Area of Test Strip.	Temperature. Fahrenheit.	Breaking Weight per Sq. In. of original Section.	Area of Strip at Fracture.	Reduction of Area.	Permanent Extension in a Length of 6¼ ins.	Remarks.
	Ins. In.		Square ins.	°	Tons.	Square in.	Per cent.	Per cent.	
1	Flat bar iron 4½ × ½	Hull Forge Co.	0·75	5	24·80	0·60	20·0	22·8	
2	" "	"	0·75	5	24·57	0·61	18·8	22·0	
3	" "	"	0·75	5	24·29	0·59	21·7	14·7	For appearance of fracture, see accompanying diagram, Plate 2.
4	" 6 × ½	"	0·75	5	23·38	0·56	25·6	20·8	
5	" "	"	0·75	5	25·37	0·60	20·0	21·0	
6	" "	"	0·75	5	22·18	0·60	20·0	12·6	
	Average		0·75	5	24·09	0·59	21·7	19·8	
7	Flat bar iron 4½ × ½	Hull Forge Co.	0·75	50	25·00	0·56	25·6	20·2	
8	" "	"	0·75	5	22·76	0·66	12·0	11·8	Broke through neck—not included in average.
9	" "	"	0·75	5	23·68	0·65	13·3	16·1	
10	" 6 × ½	"	0·75	5	24·73	0·63	16·1	19·1	
11	" "	"	0·75	5	25·00	0·63	16·1	18·6	
12	" "	"	0·75	5	24·38	0·62	17·5	19·8	
	Average		0·75	50	24·26	0·62	17·5	18·7	

TABLE II.—EFFECTS of TEMPERATURE on the TENSILE STRENGTH of STEEL.

Number of Test.	Description of Material.	Makers' Name.	Original Sectional Area of Test Strip.	Temperature. Fahrenheit.	Breaking Weight per Sq. In. of original Section.	Area of Strip at Fracture.	Reduction of Area.	Total Permanent Extension.	Remarks.
	Ins. In.		Sq. inch.	°	Tons.	Sq. inch.	Per cent.	Per cent.	
1	Bessemer steel flat bar $4\frac{1}{2} \times \frac{3}{8}$	Messrs. Brown, Bailey, & Dixon	0·62	5	45·12	0·40	36·0	19·2	The bars contracted more in centre than at the edges, as shown in sections of fracture on Plate 3.
2	” ”	”	0·62	5	45·84	0·38	38·5	20·3	
3	” ”	”	0·62	5	47·61	0·42	32·2	20·1	
4	” ”	”	0·62	5	45·87	0·46	25·6	20·0	
5	” ”	”	0·62	5	47·60	0·46	25·6	16·5	
6	” ”	”	0·62	5	45·74	0·42	32·2	17·0	
	Average		0·62	5	46·29	0·42	32·2	18·8	
	Ins. In.								
7	Bessemer steel flat bar $4\frac{1}{2} \times \frac{3}{8}$	Messrs. Brown, Bailey, & Dixon	0·62	50	46·75	Not measured	..	..	Broke at neck thus—
8	” ”	”	0·62	50	46·64	0·43	31·2	15·6	
9	” ”	”	0·6	50	45·48	0·43	31·2	15·9	
10	” ”	”	0·62	50	..	..	..	..	Broke through neck—no measurements recorded.
11	” ”	”	0·62	50	..	..	..	..	Broke through neck—results not included in average.
12	” ”	”	0·62	50	45·66	0·40	36·0	14·9	
	Average		0·62	50	46·13	0·42	32·2	15·4	

TABLE III.—EFFECTS of TEMPERATURE on the TENSILE STRENGTH of MALLEABLE CAST IRON.

Number of Test.	Description of Material.	Makers' Name.	Original Sectional Area of Test Strip.	Temperature. Fahrenheit.	Breaking Weight per Sq. In. of original Section.	Total Permanent Extension.	Reduction of Area.	Remarks.
			Square in.	°	Tons.	Per cent.		
1	Test bar cast to shape	Messrs. Andrew Handyside, & Co., Derby	0·75	50	24·6	2·0	The reduction was so small that it was not recorded, but in no case did it exceed 2 per cent.	
2	" "	"	0·75	50	24·0	1·0		Broke through eye—no flaw.
3	" "	"	0·75	50	24·2	2·5		
4	" "	"	0·75	50	17·6	2·1		
5	" "	"	0·75	50	23·5	1·7		
6	" "	"	0·75	50	25·2	1·5		Broke through eye—flaw in casting.
	Average of bars 1, 3, 4, and 5 . .		..	50	22·4	2·1		
7	Test bar cast to shape	Messrs. Andrew Handyside, & Co., Derby	0·75	5	23·0	2·0		
8	" "	"	0·75	5	..	..		Broke through eye—flaw in casting.
9	" "	"	0·75	5	..	..		Broke through eye—no flaw.
10	" "	"	0·75	5	21·5	1·0		
11	" "	"	0·75	5	..	..		" " "
12	" "	"	0·75	5	..	..		" " "
	Average of bars 7 and 10 . . .		..	5	22·2	1·5		

TABLE IV.—EFFECTS of TEMPERATURE on the TRANSVERSE STRENGTH of CAST IRON.

Number of Test.	Section of Test Bar.	Distance between Points of Support.	Breaking Weight.	Deflection before Fracture.	Temperature. Fahrenheit.
	Inches. Inch.	Feet.	Cwt.	Inch.	°
1	2 × 1	3	27·8	0·29	50
2	"	"	29·0	0·30	"
3	"	"	29·4	0·31	"
4	"	"	30·4	0·35	"
5	"	"	27·4	0·29	"
6	"	"	27·8	0·34	"
	Average		28·6	0·31	
7	2 × 1	3	26·4	0·23	5
8	"	"	23·4	0·24	"
9	"	"	Not broken	..	"
10	"	"	29·4	0·27	"
11	"	"	31·8	0·31	"
12	"	"	28·4	0·29	"
	Average		27·8	0·26	

NOTE.—Owing to an irregularity in the casting, bar No. 9 would not enter the testing machine, and was not broken.

TABLE V.—EFFECTS of TEMPERATURE on CAST-IRON BARS WHEN SUBJECTED to IMPACT.

Weight of monkey . . . . 10 lbs.

Number of Test.	Length of Bar.	Section of Bar.	Distance between Points of Support.	Height of Fall required to Break the Bar.	Temperature. Fahrenheit.
	Inches.	Inches. Inch.	Inches.	Feet. Inches.	°
1	10	2 × 1	6	3 9	5
2	"	"	"	3 7	"
3	"	"	"	3 5	"
4	"	"	"	3 10	"
5	"	"	"	4 4	"
6	"	"	"	3 8	"
	Average			3 9	
7	10	2 × 1	6	5 0	50
8	"	"	"	4 8	"
9	"	"	"	4 9	"
10	"	"	"	4 11	"
11	"	"	"	4 9	"
12	"	"	"	4 7	"
	Average			4 9⅓	

TABLE VI.—EFFECTS of TEMPERATURE on WROUGHT-IRON BARS WHEN SUBJECTED to IMPACT.

Length of test bars . . . 18 inches. Distance between points of support . 6 inches.
Section of „ . . . ¾ inch square. Weight of monkey . . . . 40 lbs.

Temperature 50° Fahrenheit.

No. of Test	1		2		3		4		5		6	
No. of Blow.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.
	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	In.	Ft. ins.	Inch.
1	4 0	0·20	3 0	0·08	3 0	0·12	4 0	0·14	4 0	0·16	4 0	0·22
2	4 6	0·28	3 6	0·20	3 6	0·24	4 6	0·32	4 6	0·36	4 6	0·34
3	+	broke	4 0	0·32	4 0	0·34	5 0	0·52	5 0	0·50	5 0	0·44
4	..	..	4 6	0·42	4 6	0·50	+	broke	5 6	0·64	5 6	0·64
5	..	..	5 0	0·56	5 0	0·60	..	..	6 0	0·84	+	broke
6	..	..	5 6	0·76	5 6	0·84	..	..	6 6	1·10	..	..
7	..	..	+	broke	6 0	0·98	..	..	+	broke	..	..
8	..	..	..	..	+	broke	..	..	..	..	..	..

Average ultimate fall . . 5 feet 6 inches.
„ „ deflection . 0·71 inch.

Temperature 5° Fahrenheit.

No. of Test	7		8		9		10		11		12	
No. of Blow.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.
	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	In.	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.
1	6 0	0·28	5 0	0·52	4 0	0·10	3 0	0·08	3 0	0·24	3 0	0·06
2	7 0	0·52	+	broke	4 6	0·38	3 6	0·18	3 6	0·28	3 6	0·18
3	+	broke	..	..	+	broke	4 0	0·34	4 0	0·48	4 0	0·32
4	..	..	..	..	..	..	4 6	0·44	4 6	0·54	4 6	0·48
5	..	..	..	..	..	..	+	broke	5 0	0·70	5 0	0·64
6	..	..	..	..	..	..	..	..	+	broke	5 6	0·80
7	..	..	..	..	..	..	..	..	..	..	6 0	0·92
8	..	..	..	..	..	..	..	..	..	..	+	broke

Average ultimate fall . . 5 feet 4 inches.
„ „ deflection. 0·58 inch.

Table VII.—Effects of Temperature on Steel Bars when subjected to Impact.

Length of test bars . . . 18 inches.
Section of „ . . . 1 inch square.
Distance between points of support . 6 inches.
Weight of monkey . . . . . . 40 lbs.

Temperature 50° Fahrenheit.

No. of Test	1		2		3		4		5		6	
No. of Blow.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.
	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	In.	Ft. ins.	Inch.
1	1 0	0·04	1 0	0·02	2 0	0·00	4 0	0·02	4 0	0·18	2 0	0·00
2	1 6	0·05	1 6	0·06	3 0	0·01	4 6	0·04	5 0	0·22	3 0	0·08
3	2 0	0·06	2 0	0·08	4 0	0·08	5 0	0·05	6 6	0·42	4 0	0·14
4	2 6	0·08	2 6	0·12	5 0	0·22	5 6	0·10	7 6	0·62	5 0	0·16
5	3 0	0·14	3 0	0·18	+	broke	6 0	0·22	8 0	0·68	6 0	0·18
6	3 6	0·16	3 6	0·20	..	..	6 6	0·24	9 0	0·84	+	broke
7	4 0	0·18	4 0	0·22	..	..	7 0	0·34	10 0	0·98	..	..
8	4 6	0·20	5 0	0·26	..	..	7 6	0·36	11 0	1·20	..	..
9	5 0	0·25	5 6	0·30	..	..	8 0	0·48	12 0	1·34	..	..
10	+	broke	6 0	0·34	..	..	8 6	0·62	13 0	1·56	..	..
11	..	..	6 6	0·40	..	..	9 0	0·72	14 0	1·60	..	..
12	..	..	7 0	0·46	..	..	9 6	0·80	+	broke	..	..
13	..	..	+	broke	..	..	+	broke	..	..	..	..

Average ultimate fall . . 7 feet 9 inches.
„ „ deflection . 0·59 inch.

Temperature 5° Fahrenheit.

No. of Test	7		8		9		10		11		12	
No. of Blow.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.
	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	In.	Ft. ins.	Inch.	Ft. ins.	Inch.
1	1 0	0·00	3 0	0·01	2 0	0·00	4 0	0·02	3 0	0·01	3 0	0·01
2	2 0	0·01	3 6	0·02	2 6	0·01	5 0	0·10	4 0	0·02	4 0	0·08
3	3 0	0·02	4 0	0·08	3 0	0·04	6 0	0·28	4 6	0·06	5 0	0·16
4	3 6	0·04	4 6	0·12	3 6	0·06	7 0	0·38	5 0	0·10	5 6	0·26
5	4 0	0·06	+	broke	4 0	0·10	8 0	0·52	5 6	0·14	6 0	0·30
6	4 6	0·10	..	..	4 6	0·12	9 0	0·62	6 0	0·16	6 6	0·42
7	5 0	0·14	..	..	5 0	0·20	10 0	0·78	6 6	0·20	7 0	0·46
8	5 6	0·20	..	..	5 6	0·24	11 0	0·88	+	broke	7 6	0·50
9	6 0	0·28	..	..	6 0	0·30	12 0	1·02	..	..	8 0	0·64
10	6 6	0·34	..	..	6 6	0·40	12 6	1·04	..	..	8 6	0·72
11	+	broke	..	..	+	broke	13 0	1·10	..	..	+	broke
12	..	..	..	..	..	..	13 6	1·18				
13	..	..	..	..	..	..	+	broke				

Average ultimate fall . . 7 feet 8 inches.
„ „ deflection. 0·49 inch.

TABLE VIII.—EFFECTS of TEMPERATURE on MALLEABLE CAST-IRON BARS WHEN SUBJECTED to IMPACT.

Length of test bars . . . 3 feet 6 inches.
Section of „ . . . 1¼ inch × ⅝ inch.

Distance between points of support . 18 inches.
Weight of monkey . . . . . . 40 lbs.

Temperature 50° Fahrenheit.

No. of Test	1		2		3		4		5		6	
No. of Blow.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.
	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.
1	1 0	0·08	3 0	0·12	4 0	0·26	4 0	0·22	4 0	0·16	4 0	0·14
2	2 0	0·12	4 0	0·24	5 0	0·32	5 0	0·30	5 0	0·30	5 0	0·42
3	3 0	0·26	5 0	0·42	6 0	0·48	6 0	0·44	6 0	0·44	+	broke
4	4 0	0·38	6 0	0·60	7 0	0·64	7 0	0·62	7 0	0·56	..	..
5	5 0	0·50	7 0	0·76	8 0	0·82	7 6	0·70	8 0	0·72	..	..
6	6 0	0·82	8 0	0·90	+	broke	8 0	0·84	8 6	0·86	..	..
7	7 0	0·96	+	broke	..	..	8 6	0·98	9 0	0·96	..	..
8	8 0	1·04	..	..	..	..	+	broke	+	broke	..	..
9	9 0	1·18	..	..	..	..	..	..	..	..	..	..
10	+	broke										

Average ultimate fall . . 7 feet 11 inches.
„ deflection . . . 0·88 inch.

Temperature 5° Fahrenheit.

No. of Test	7		8		9		10		11		12	
No. of Blow.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.	Height of Fall.	Permanent Deflection.
	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.	Ft. ins.	Inch.
1	4 0	0·14	4 0	0·20	4 0	0·20	4 0	0·14	4 0	0·12	4 0	0·18
2	5 0	0·24	5 0	0·30	5 0	0·40	5 0	0·16	5 0	0·32	5 0	0·38
3	6 0	0·50	6 0	0·50	6 0	0·54	6 0	0·36	6 0	0·54	+	broke
4	7 0	0·64	7 0	0·62	7 0	0·68	7 0	0·40	7 0	0·64	..	..
5	7 6	0·78	7 6	0·81	7 6	0·82	7 6	0·50	8 0	0·68	..	..
6	8 0	0·82	+	broke	+	broke	8 0	0·60	8 6	0·92	..	..
7	+	broke	..	..	..	..	8 6	0·66	+	broke	..	..
8	..	..	..	..	..	..	9 0	0·76				
9	..	..	..	..	..	..	+	broke				
10												

Average ultimate fall . . 7 feet 7 inches.
„ deflection . . . 0·75 inch.

TABLE IX.—SUMMARY of RESULTS.

TENSILE STRAINS. (For details see Tables I., II., and III.)

Description of Material.	Sectional Area of Test Bar.	Average Breaking Weight per Square Inch.	Average Permanent Extension in Length of 6½ inches.	Average Reduction of Area.	Temperature. Fahrenheit.
Inches. Inch.	Sq. inch.	Tons.	Per cwt.	Per cent.	°
Wrought-iron flat bars {6 × ⅛, 4½ × ⅙}	0·75	24·09	19·8	21·7	5
" " "	0·75	24·26	18·7	17·5	50
Bessemer steel " 4½ × ⅛.	0·62	46·29	18·8	32·2	5
" " "	0·62	46·13	15·4	32·2	50
Malleable cast iron	0·75	22·20	1·5	..	5
" "	0·75	22·40	2·1	..	50

TRANSVERSE STRAINS. (For details see Table IV.)

Description of Material.	Sectional Area of Test Bar.	Distance between Points of Support.	Average Breaking Weight per Square Inch.	Average Deflection before Fracture.	Temperature. Fahrenheit.
Feet. Ins. Feet. Inch.	Sq. Inches.	Feet.	Cwt.	Inch.	°
Cast-iron bars, 3 6 × 2 × 1 .	2	3	27·8	0·26	5
" " " "	2	3	28·6	0·31	50

IMPACT. (For details see Tables V., VI., VII., and VIII.)

Description of Material.	Section of Test Bar.	Distance between Points of Support.	Average Height of Fall.	Average Permanent Deflection.	Temperature. Fahrenheit.
	Sq. Inches.	Inches.	Feet. Ins.	Inch.	°
Wrought-iron bars	⅞	6	5 4	0·58	5
" "	⅞	6	5 6	0·71	50
Best cast tool steel bars . .	1	18	7 8	0·49	5
" " . .	1	18	7 9	0·59	50
Malleable cast-iron bars . .	1½ × ¾	18	7 7	0·75	5
" " . .	1½ × ¾	18	7 11	0·88	50
Cast-iron bars	2 × 1	6	3 9	Not perceptible.	5
"	2 × 1	6	4 9½		50

TABLE X.

Chemical Analyses of the Materials used in the Experiments.[1]

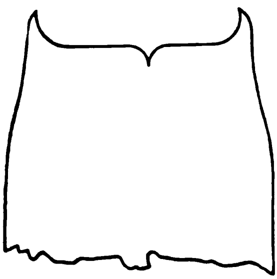
Materials.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Graphite.	Iron (by Difference).	Total.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Bessemer steel	0·400	0·079	0·107	0·044	1·001	..	98·369	100·000
Cast tool steel	1·145	0·121	0·042	0·013	0·197	..	98·482	100·000
Best bar iron .	0·060	0·158	0·073	0·256	trace	..	99·453	100·000
Malleable cast iron . . .	2·085	0·499	0·446	0·021	0·183	..	96·766	100·000
Ordinary cast iron . . .	0·300	1·618	0·119	1·107	0·563	2·643	93·650	100·000
Common bar iron . . .	0·067	0·136	0·036	0·347	0·016	..	99·398	100·000

[1] These analyses were made by Mr. Edward Richards, F.I.C., Chemist to the Barrow Hæmatite Steel Company, Limited.

Discussion.

Mr. Webster. Mr. WEBSTER said that in testing steel bars by tensile strain the resulting fracture was peculiar. In Fig. 1, it would be noticed that the curve on the top of the bar was very similar to that which was produced when the bar was subjected to impact. Four out of the twelve bars broke as shown in the figure.[1]

FIG. 1.



Mr. Bell. Mr. LOWTHIAN BELL, M.P., said his experience had been rather in the direction of manufacturing iron than in testing it after it was made, that portion of the business being left to the civil engineer. As a rule, iron manufacturers could form a pretty correct notion of the value of the article they produced without having recourse to elaborate experiments. But he would venture to offer one or two remarks on the mistake which he believed was made when persons spoke of crystalline and fibrous iron. He believed that it had yet to be proved that iron, in its ordinary condition, was fibrous. The structure of iron was necessarily crystalline. Of course engineers were in the habit of judging the quality of iron by the character of the crystals, and they knew well that when iron broke with a face of large crystals, that was a clear indication of inferiority in the quality of the metal. But what constituted the difference between good iron and bad? As a rule, he imagined it was not far from the truth to assume that good iron was pure iron, and that bad iron was impure. It was well known to those who had studied chemistry, that a mixture of materials of different qualities was generally more fusible than any of the substances composing it when taken separately. Iron, associated with 1 per cent. of phosphorus, silicon, carbon, and sulphur, would be more readily affected by heat than chemically pure iron; and it was well known to all practical iron makers, the workmen themselves, that inferior iron was unable to "stand the heat"—to use a phrase well known in the forge. That meant that iron so constituted, approaching more nearly, he would not say to fusion, but at all events to a semi-pasty condition,

[1] Since the reading of the Paper, the Author has had a chemical analysis made of all the samples used in the experiments, the results of which are given in Table X.

in consequence assumed more readily a crystalline fracture in cooling than would a material which had not been softened by the action of heat. The consequence was that there were crystals of considerable size, owing, of course, to the greater mobility of the particles of matter constituting the bar when raised to a high temperature. If, on the other hand, iron was pure, and was not affected by heat to the same extent as impure iron, the opportunity which the metal had of forming large crystals was considerably diminished, and the crystals were small, but in each case there was a crystalline structure. The ordinary mode of testing a bar of iron by fracture, was to make a nick on one side, and to bend it by the action of a hammer; and then commenced what he believed to be the formation of fibre, supposing the quality of the iron to be such as would admit of its formation. If the iron happened to be in large crystals, each crystal presenting a large facet, then, instead of that wire-drawing process going on, there was an abrupt separation, and the iron broke through at right angles to its length —a clean break of crystalline iron. If, on the other hand, the iron was of a ductile character so as to permit the wire-drawing or elongation of its particles, then there was a development of fibre. The late Mr. Brunel had remarked that in the same bar of iron, a fibrous or a crystalline fracture might be obtained at will, ten times, by the application of heat. Mr. Lowthian Bell went further, and said that there might be ten fractures in the bar, five of them crystalline, and five of them fibrous, at the same temperature. If, instead of giving the bar an opportunity of being wire-drawn in the way he had explained, it was nicked all round and then was submitted to a forcible blow, the bar, which under other circumstances would break quite fibrous, would exhibit a crystalline fracture. He therefore inferred that, in iron as it came from the rolls under ordinary circumstances, there was no such thing as fibre. There was a rough mode of testing iron in rolling-mills by nicking and bending it; but it could not be classed with such experiments as had been described, and the question was one that could only be satisfactorily settled by elaborate and careful experiments. Every practical man knew that iron, when it was warmed, showed under those circumstances more fibre than the same iron did in its cool state, and no man who wished to exhibit iron would think of cooling it to 5° Fahrenheit before he asked his customer to inspect the fracture. The fact was, that the molecules of iron acquired a certain amount of mobility as they approached a high temperature, until ultimately they were so mobile as to enter into fusion. With a warm bar of iron the Mr. Bell.

Mr. Bell. wire-drawing process was effected with greater ease than it would be if the iron were cool. He believed some fractures might be accounted for by coldness in the weather, when the iron was less liable to be drawn; but he agreed with the Author that, unless the force were applied in the direction to which he had alluded, frost would probably not make much difference in good iron. Of course the matter was very different when frost was applied to a railway tire, shrunk on to a somewhat rigid centre, where the mere contraction of the iron greatly increased the strain upon its parts.

Mr. Williams. Mr. EDWARD WILLIAMS said he was a maker of iron and steel rather than an engineer using them. He thought the views of Mr. Bell were very much those of practical iron and steel makers. Long experience in making and testing rails had convinced him that they broke more readily when very cold, than when above freezing point. The results arrived at by the Author were such as might have been expected, namely, that bars in a frozen state would stand a high tensile strain without elongation, and that they would break readily under impact. He agreed with Mr. Bell in reference to fibre and crystals. He believed that there was no fibre in iron until it was produced by bending. This he had proved, at least to his own satisfaction. At Dowlais in his time there was a most efficient testing machine in the shape of a very steep inclined plane, on which there were occasional wild runs that smashed up into small bits all the wagons let loose. For many years he made the axles, tires, and ironwork generally of those wagons as good and as strong as possible, and samples of the several parts were doubled up cold with scarcely a sign of cracking; but the inclined plane accidents broke all up short as though it had been of the commonest quality. The fact he believed to be that, under a force enormously beyond that which iron could bear, it always broke off short; and, on the contrary, where the iron began by bending, there was fibre. Reference had been made in the Paper to two samples of tool steel that gave very different results, and it was stated that the steel was rolled. He knew nothing more difficult to roll than hard steel, because of the delicate heating required, and he was inclined to think that this was the cause of the widely different behaviour of the samples.

Colonel Greck. Colonel P. GRECK said his experience quite confirmed the results obtained by Mr. Webster. The effect of cold on iron and steel, especially on iron, was very great, and he had had ample proof of it in his own country (Russia), where the breakages had been so numerous that it was necessary to use particularly soft steel.

Colonel Greck.

Of late years the Government had required that all rails should be tested at a temperature of about 34° Fahrenheit below freezing point, or 2° below zero. He had had occasion to make many experiments, both in England and in Germany, and he had always found that the deflections under blows were smaller when the rail was subjected to a temperature of zero or below, than under the temperature of 55° or 65° above. He had a record of some tests conducted last year at the Osnabrück Steel Manufactory, with a rather light rail, 35 lbs. to the yard, from a narrow-gauge railway, as shown in the accompanying Table. The rails were cut in 6-feet

RECORD of TESTS MADE at OSNABRÜCK on the 23rd of JULY, 1879, on STEEL RAILS at ORDINARY and at LOW TEMPERATURES.

The height of fall was 1 mètre, and the deflection is in millimètres.

Number of Rails.	Temperature of Rails Tested + 60¾° Fahrenheit.				Temperature of Rails Tested − 8¼° Fahrenheit.				Observations.
	First Blow.	Second Blow.	Third Blow.	Fourth Blow.	First Blow.	Second Blow.	Third Blow.	Fourth Blow.	
	Millimètres.	Millimètres.	Millimètres.	Millimètres.	Millimètres.	Millimètres.	Millimètres.	Millimètres.	
1	52	107	154	200	44	88	132	..	Weight of rails, 35 lbs. per yard. Length of pieces tested, 6 feet. Distance of supports, 3 feet 6 inches. Weight of monkey, 935 kilogrammes = 18·4 cwt. From each rail two pieces 6 feet long were cut, and both pieces were tested by impact, one at ordinary temperature, and the other at a temperature artificially lowered, by keeping the piece in a mixture of ice and salt.
2	48	98	144	191	44	87	127	177	
3	52	105	153	..	46	89	133	..	
4	54	107	155	..	45	91	134	..	
5	52	103	150	201	43	84	128	174	
6	52	102	150	201	45	87	134	..	

pieces. One piece was tested at the ordinary temperature of 60¾° Fahrenheit, and another piece of the same rail was frozen in a mixture of snow and ice at a temperature of 40¼° Fahrenheit below freezing point. They were then subjected to blows from a weight of 935 kilogrammes, or nearly 19½ cwt., falling from a small height. The first blow on the iron at the ordinary temperature produced a deflection of 52, and the same blow on the other piece a deflection of 44, showing a difference of 16 per cent. A second experiment showed a diminution of from 16 to 20 per cent. in the deflection when the rail was warm. He found that there was

Colonel Greck. no appreciable difference in the results from tensile strain under a cold or a warm temperature. The breakages of steel tires in Russia were 50 per cent. more in winter than in summer; but the greatest breakage did not occur on the day of a severe frost, but usually a day or two after, when there was a change of temperature. That, he thought, must be ascribed partly to the overheating of the tire when it was set on the wheel, and partly to the fact that the permanent way in cold countries was always much worse at the moment of a change of temperature.

Mr. Bamber. Mr. E. F. BAMBER observed that, setting aside the chemical consideration of the subject, and treating it only from a physical point of view, it would appear that certain statements might be made *à priori* with regard to the influence of heat upon metals. Such and such results might be predicated, which experiment should afterwards prove correct. Of this class were the following:—(1.) There was a certain temperature of a material body, which might be called the temperature of normal strength, and this was the temperature at which the molecules arranged themselves during manufacture; it would be under ordinary circumstances that temperature of the atmosphere of the factory at which the material cooled in settling into the solid state. The value of the consideration of such a temperature was that, if the material had little range of strength, it would be most advantageous to employ it in a climate where the average temperature of the atmosphere did not differ widely from the temperature of normal strength. In this connection, it might be added, that if pieces of a structure which had been manufactured at a temperature varying much from the temperature at which they were to be employed, *e.g.* rails made in winter in Great Britain to be used in a tropical climate, the best guarantee of strength would probably be, to anneal the pieces in the climate in which they were to be used, as the action of annealing appeared to be equivalent to re-manufacture. It would probably conduce to economical wear (if market exigencies would allow it) to send winter-made stuff to a cold climate, and summer-made to a warm, when it was inconvenient to follow the action of annealing. (2.) Homogeneous material which had to bear a strain of extension would diminish in strength with a rise of temperature above its temperature of normal strength, in a certain, probably in an arithmetical, proportion, for every degree; while it would increase in strength with a fall of temperature through its range of strength in both directions. That this was so might be made evident by the consideration that the mode of action of heat and of a strain of extension was in both cases the same,

i.e. to cause, or tend to cause, a separation of the ultimate molecules of the substance. (3.) Homogeneous material, which had to bear a strain of compression, would increase in strength with a rise of temperature above its temperature of normal strength, while it would diminish in strength with a fall of temperature through its range of strength in both directions. In this instance the physical and mechanical actions were in opposition; hence the strength was increased when they were thus opposed, and diminished when they worked together. (4.) It was not easy to predicate the effect of variation of temperature upon homogeneous matter under transverse strain, as it would be a function of the two preceding cases. If the figure of the piece had been designed for greatest strength, then, where most material had been thrown into the lowest member, the piece would increase in strength with a fall in temperature, and would diminish in strength with a rise of temperature above its temperature of normal strength within its range of strength. But when the material of the piece had not been so arranged, and remembering always that the reliable strength of a piece was that of its weakest part, a fall of temperature would certainly diminish, and a rise of temperature possibly increase its strength. This might be considered to be the case of reversible rails, made with the upper and lower flanges of the same size and section. Thus, if, in the case of a rail, it was assumed that the upper flange and web together were to the lower flange in the proportion of 5 to 4, which was about the proportion of the resistance of its material to extension and compression, then the neutral axis would be at the junction of the lower flange with the web, a fall of temperature would diminish the strength of $\frac{5}{9}$ of the material under compression, and increase the strength of $\frac{4}{9}$ of it under extension. If the rail should be considerably worn before reversal, the neutral axis might rise so high as either to modify the effect of fall of temperature below that of normal strength, or even to produce the effect of increasing the strength of the rail, by bringing a larger portion of the material under extension than under compression. (5.) Heterogeneous material, or homogeneous material, which had only a small range of strength, would be affected considerably by variation in temperature, and its ultimate effect could not be predicated, as the molecules would be easily removed from their original position, and it was not possible to indicate what new position they might take up. For instance, in a piece of cindery iron the effect might be to move the molecules of cinder out of the line of direct strain, substituting in their place metal, and thus to increase the strength of the piece, or by Mr. Bamber.

Mr. Bamber. producing the opposite effect, to diminish it. (6.) With regard to the influence of variation of temperature upon resilience, or that property of matter which resisted vibration, &c., it might be stated that, although pieces were made of double strength to resist dynamic as compared with static strain, temperature variations would influence both proportionally. For pieces under vibration were under a certain amount of play, and as variation in temperature increased or diminished this amount of play, setting a physical as well as a mechanical influence at work, and thus bringing the material more quickly within the limits of its proof-resistance to vibration, it would appear that the same allowances must be made for the influence of temperature for dynamic strain as had already been indicated in the case of static strain, even after the material of the piece had been doubled. (7.) All the existing moduli of resistance to extension, compression, and bending, and the moduli of elasticity and resilience in regard to these tests of strength, could only be considered as of mean or average value, as the temperatures at which the experiments had been made, from which the moduli had been deduced, were not allowed for. Since, in the latter case, when the moduli of elasticity were under consideration, if the intensity of the stress were kept constant (when testing homogeneous material within its proof strength), the extension would be found to vary with the temperature, to increase as it rose, and to diminish as it fell; whilst if the proportional elongation or measure of the strain were kept relatively the same at all temperatures, the intensity of the stress would be found to vary with the temperature, and as the modulus was the ratio of the intensity of the stress to the proportional extension, it must also vary with the temperature. That the extension of a piece of material would increase with a rise of temperature, and diminish with a fall of temperature, could be made mentally evident by supposing a current of electricity to be passing through and heating a wire under extension, when it would evidently be elongated more under the same weight than another exactly similar piece kept at atmospheric temperature. (8.) The object of these remarks was to show the necessity of making the thermometer the constant companion of the testing machine, and perhaps also a necessary appendage in the works. In experimenting on ultimate or proof strength, instead of attempting to make the experiments at certain fixed temperatures, it would probably be found both more easy, satisfactory, and economical, to conduct them at atmospheric temperature, as this varied with season and climate, and thence to deduce curves from which

formulæ and moduli, at a certain fixed or standard temperature, might be calculated. Mr. Bamber.

Mr. C. DOUGLAS FOX remarked that in North America, where he had had some experience, there was a great variation of temperature between summer and winter, the temperature sometimes falling in winter to 30° or 40° below zero. His experience bore out that of Colonel Greck as to the effect of low temperature producing a large number of fractures, especially of steel tires, where the skeletons were rigid cast iron or wrought iron; but that did not apply to the cast iron used for wheels in America. The wheels made of that iron stood marvellously well, even under very severe temperatures. Similar experiments would be valuable if applied to bars and other objects of a larger size. The size in the cases mentioned by the Author was so small that he thought there was a liability to local error, so that the results would not be so satisfactory as they otherwise might be. The number of the test bars in each case was also comparatively small. Experiments with full-sized bars, and at a lower range of temperature, would be of great use to those who had to deal with structures subjected to heavy shocks under different temperatures. He thought that in the experiments there ought to be a range of from 30° below zero up to at least 120° Fahrenheit above. Even in England during the winter of 1879–80 there had been lower temperatures than those mentioned in the Paper, and in the summer the temperature occasionally rose to 120° in the sun. Mr. Fox.

Mr. W. ATKINSON said it was on record[1] that in one winter four thousand rails broke on the Grand Trunk railway, Canada, when the line was about 1,400 miles in length. With regard to the question of extremes of temperature, a Paper had been read at the Literary and Philosophical Society of Manchester in 1871 by Mr. Brockbank, giving the results of experiments such as Mr. Fox desired.[2] It was found at the Darlington works that the rails contracted for for the East Indian Railway Company in 1869, which were of a very superior quality, would not stand the tests in the colder weather; and the company naturally wished to ascertain whether it depended upon any defect in the iron or upon any peculiar conditions of the temperature. Ten rails were taken out of a batch of one thousand, and four of them were warmed to a temperature of 120°, each of which was tested with a falling weight of Mr. Atkinson.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 404.
[2] *Ibid.*, vol. x., p. 77.

Mr. Atkinson. 2,000 lbs. from a height of 5 feet, then with a second blow from a height of 5 feet, and then with a third blow from a height of 7 feet. Not one of the rails broke. Six rails were next taken at a temperature of 26°—the temperature of the atmosphere at the time. One of them stood the three tests, four of them broke with the second 5-feet blow, and one broke with the first 5-feet blow. The other experiments entirely confirmed those given by the Author. Mr. Brockbank's Paper was followed by a record of some experiments by Sir William Fairbairn on plate iron and cast iron, in which it was found that between the temperature of zero and 400° with plate iron there was very little difference in the tensile strain, but with bar iron with the higher temperatures a much higher result was obtained—in some cases as much as 39 tons per square inch. Mr. Brockbank tried the experiment of impact, because he felt satisfied that tension and torsion were extremely uncertain on account of the heat acquired during the operation.

Mr. Mosse. Mr. J. R. Mosse was for several years engineer and manager of the Nova Scotia Government railways, and during that time there had been some very severe frosts. In January there was generally a severe snowstorm with perhaps 2 feet of snow on the ground. In the middle of the month there would come a thaw with a south-west wind for a couple of days, followed by rain in torrents for ten hours; then the rain would suddenly cease, and the wind veer to the north, and the thermometer, in perhaps six or eight hours, would go down to zero. A large portion of melted snow from the slopes of the cuttings would come upon the rails, and in extreme cases ice 3 feet thick would sometimes be found on the rails on the following morning; so that the only way of getting along was to cut the ice away with an axe. During that time the rails would rise 6 inches in a night, and he had sometimes known the rails to rise as much as 1 foot in the same time. The chairs were of the ordinary size, and the rails were fitted to them by Ransome and May's compressed keys of elm or oak. The number of chairs that broke in the winter was excessive, he believed as many as six thousand per annum on a length of 90 miles. Eventually that system of road was discontinued, and the American system was adopted. The tires of the wheels used to crack, though, strangely enough, never at the time of severe frost, but soon after the thaw commenced. On one occasion there were three engines in the running shed, which it was believed would suffice for any emergencies, but one night, after a severe frost, when the weather began to moderate, a Low-moor tire of each of these engines cracked. He did not remember

a single case of the chilled cast-iron wheels having cracked. The chairs broke both in the lip and in the bed, chiefly in the latter; and as they did not thus break in mild weather, it would seem that cast iron was rendered peculiarly brittle by severe frost. Mr. Mosse.

Mr. J. A. LONGRIDGE thought the Author had drawn a wrong inference from his experiments upon impact. In Table VI., with reference to the iron bar subjected to impact, he gave the average ultimate fall as 5 feet 6 inches, and the average deflection as 0·71 inch, taking those averages by adding together the whole of the final falls and deflections. That, he thought, was not the way in which such averages should be taken, particularly when there was such an enormous discrepancy in the bars as to the actual weight which broke them, and the deflections. He thought it would be better to take the amount of work done upon each bar—to take all the falls multiplied into the weight, which would give the work done upon the bar, and then, for each bar, to ascertain how many foot-pounds it required to give, say, $\frac{1}{100}$ inch deflection. He had treated the Tables in that way, excluding from the bars in Table VI., at 5° Fahrenheit, Nos. 8 and 9, which appeared to have been abnormal in their condition, not at all corresponding with the other bars, and he found the following results: With iron bars at 50°, in order to get $\frac{1}{100}$ inch deflection, it required 1,203 foot-pounds, and at 5°, 1,170 foot-pounds, so that the work done to give a certain deflection was less in the cold than in the hot bar, which was the reverse of the conclusion arrived at by the Author. Again, taking steel bars, Table VII., and excluding for the same reason Nos. 3 and 5 at 50°, and Nos. 8 and 11 at 5°, he found that in order to get $\frac{1}{100}$ inch deflection at 50° it required 4,236 foot-pounds, whereas at 5° it only required 4,061 foot-pounds, again showing a less amount of work to give deflection in the cold bar than in the hot. In the case of malleable cast iron, Table VIII., he found that with the bar at 50° it took 1,652 foot-pounds $\frac{1}{100}$ inch deflection, and at 5°, excluding bar No. 10, 1,570 foot-pounds. So that in all cases, measuring by the work done, the deflection was produced with a less amount of work in the case of the cold bar than in the case of the hot bar. The conclusion arrived at by the Author, by taking an average, was that the reduction of flexibility was about 18 per cent. in cast iron, 17 per cent. in steel, and 15 per cent. in malleable cast iron, which was at variance with what Mr. Longridge considered to be the right deduction to be drawn from the experiments. The annexed Tables showed the work done, and deflection in each bar. Mr. Longridge

Mr. Longridge.

IRON (TABLE VI.).

Temperature 50° Fahrenheit.				Temperature 5° Fahrenheit.			
Number of Bar.	Work Done in Foot-Pounds.	Final Deflection in $\frac{1}{100}$ Inch.	Work Done for $\frac{1}{100}$ Inch.	Number of Bar.	Work Done in Foot-Pounds.	Final Deflection in $\frac{1}{100}$ Inch.	Work Done for $\frac{1}{100}$ Inch.
1	340	28	1,213	7	520	52	1,000
2	1,020	76	1,343	8*	200	52	390
3	1,260	98	1,286	9*	340	38	890
4	540	52	1,040	10	560	44	1,275
5	1,260	110	1,145	11	800	70	1,143
6	760	64	1,188	12	1,260	92	1,261
Average work done for each $\frac{1}{100}$ inch . . .			1,203	Average work done for $\frac{1}{100}$ inch, omitting Nos. 8 & 9			1,170

STEEL (TABLE VII.).

1	1,080	25	4,320	7	1,640	34	4,822
2	1,900	46	4,134	8*	600	12	5,000
3*	560	22	2,550	9	1,700	40	4,250
4	3,240	80	4,050	10	4,400	118	3,774
5*	4,000	160	2,500	11*	1,380	20	6,900
6	800	18	4,440	12	2,440	72	3,400
Average work done for each $\frac{1}{100}$ inch deflection, omitting (3) and (5) .			4,236	Average work done for $\frac{1}{100}$ inch, omitting (8) and (11)			4,061

MALLEABLE CAST IRON (TABLE VIII.).

1	1,800	118	1,526	7	1,400	82	1,708
2	1,320	90	1,466	8	1,180	81	1,454
3	1,200	82	1,450	9	1,180	82	1,450
4	1,840	98	1,870	10*	2,200	76	2,900
5	1,880	96	1,950	11	1,546	92	1,670
6	..	..	..	12	..	..	..
Average work done for $\frac{1}{100}$ inch deflection . .			1,652	Average work done for $\frac{1}{100}$ inch, omitting (10) .			1,570

SUMMARY.

—	50°.	5°.
Iron	1,203	1,170
Steel	4,236	4,061
Malleable cast iron .	1,652	1,570

* Excluded in the calculations.

Mr. Matheson.

Mr. E. Matheson remarked that the Author had made some useful experiments in regard to plain rectangular bodies, but it was a question how far those experiments elucidated what was directly interesting to engineers—the fractures that took place at low temperatures with different structures. Bars, which were free in all directions, such as those which the Author had tested, did not represent the structures of cast iron, wrought iron, and steel, which occasionally broke in cold weather. Most engineers, experienced in the manufacture of such structures, would agree that it was owing to some self-contained or initial strain in the structure from the beginning, and the experiments which the Author had described showed that the results he obtained were not sufficient to account for those fractures. Taking the worst cases of cast iron, the Author recommended engineers to allow 25 per cent. more margin of strength for the effect of cold. But as in cast-iron structures it was the habit to have a considerably greater margin, there must be some other cause for fracture, and it was due, as most founders knew, to inequalities in cooling, a self-contained strain being left in the casting without any immediate sign of it; but which, when intensified afterwards by greater cooling, caused the casting to break. So great were the effects from this cause that he had, when in Russia, heard of columns breaking simply because one side was exposed to the rays of the sun, while the other was buried in snow, a difference in temperature perhaps not greater than those the Author had had in his experiments. There was another point that he thought worthy of some elucidation. The Author had stated that all the specimens had been planed. Mr. Matheson thought that in destroying the skin of the iron the value of the experiments was greatly reduced, because in castings the skin added to the strength, and yet often had that self-contained strain in it which caused the fracture; and in wrought iron, too, the skin, though differing less with the interior than in cast iron, also had its value. If the specimens had not been planed he thought different results might have been obtained. Mr. Lowthian Bell had stated that wrought iron had no fibre in the sense ordinarily understood. But surely if the particles had been elongated, they were elongated in the process of rolling, and were in that condition when they reached the hands of the smith. All those experiments seemed to point to this, that any iron that had been recently in a fluid condition was affected much more by cold than what had gone through intermediate processes, such as puddling. There was therefore little difference in wrought iron, but there was a great

Mr. Matheson. deal in cast iron. That led to another inquiry, how far steel made by modern processes was affected by cold? because the intermediate processes between the ingot condition and the finished bar were much less than those between cast iron and rolled iron. No doubt steel, when made into ingots 8 or 10 inches wide, had much larger crystals in the middle than towards the outside; and it would be interesting to know how far those inequalities were altered or removed, or equalised by the intermediate processes of cogging, or hammering, or rolling. It had been stated some time ago, at a meeting of the Iron and Steel Institute, that ship plates broke in a remarkable manner, from causes not thoroughly understood;[1] and it was just possible that that might have been because the inequalities in the crystals had not been removed in the intermediate processes since the metal was in a fluid condition, and because the plates had some self-contained strain which became intensified by cold. It had been mentioned that the cast-iron railway wheels used in America did not break, though railway chairs broke in large numbers. It should have been stated that the wheels were made of unusually good iron, and so cooled as to be partially annealed, and therefore to some extent decarbonised and made into malleable cast iron, and these no doubt were the reasons why they did not break.

Mr. Adamson. Mr. D. ADAMSON considered that, in carrying out a series of experiments on the strength of metals at variable temperatures, engineers ought to try and get at some fundamental law, whereby the metal had arrived at its greatest density, and was then subjected to an increase or diminution of strength as it expanded or contracted from that point by change of temperature. From the investigations carried on by the Author, it appeared to be supposed that there was a peculiar property about wrought iron and steel like that of water—that when the metal was subjected to a temperature of 32° it assumed other conditions, and altered as the temperature went downwards. He hardly thought that anything of that kind took place. If any alteration were produced by heat it must be connected with the composition of the metal itself. Was there anything in the Paper that would be a guide even with regard to mechanical action? The mechanical tests were not such as he should have preferred. A piece of iron at its normal temperature carried a certain load, and a certain strain upon it produced a permanent disorganisation in the particles called permanent set; and it might certainly be expected that, by sub-

[1] *Vide* "The Journal of the Iron and Steel Institute," 1879, p. 265.

jecting the metal to a lower temperature, the process of contraction would continue, and that the first valuable indication of which one would desire to have a record would be that of permanent set, and not of total breaking force. Besides that, accurate tests with malleable metals showed that the maximum load would be carried somewhere between $\frac{5}{8}$ and $\frac{3}{4}$ of the total elongation in moderate lengths, say 8 or 10 inches. There was no indication, however, in the Paper that any of the metal tested by tensile strain possessed that property, but the specimens simply broke down with a crash when the full load was laid upon them, as was the case with bad iron, or rather a compound of iron and dirt, but not with good malleable iron or mild ingot iron. Mr. Adamson.

The best malleable iron that could be obtained commercially in this country was composed of about 99·8 per cent. of metallic iron. It possessed great ductility and exceedingly great malleability, with high welding power; it was not subject to disaster or distress by a rapid or great change of temperature. It had only a low carrying power; it took a permanent set at from $10\frac{1}{2}$ to 11 tons per sectional inch when tested in square or round bars equal to 1 square inch in area, which was a fair guide and not likely to lead to trouble by errors in calculation. It would only carry a total load of about 19 tons; but what was its behaviour while perishing? It ultimately broke down with just about the same force as produced the original permanent set, $10\frac{1}{2}$ tons. Now it would be easily understood that a highly malleable metal of that sort, at a temperature of 32°, as recorded in the Paper, would not be subjected to any serious disturbance, either in its carrying power, or in any other of its vital properties. The common commercial irons of the country imbedded pure metal to the extent of about $98\frac{1}{3}$ per cent., the rest being alloying elements of a noxious and injurious character, phosphorus in the first place, silicon in the second, and sulphur in the third. Irons so alloyed possessed the power of carrying a greater tensile load than the exceptionally pure malleable iron; they had, at least in bars, a carrying power of from 20 to 22 tons per square inch. The permanent set was at a much higher range than in the pure metal, taking place generally at between 15 and 16 tons, while there was a diminution in the power of elongation of from 30 per cent. to at most 20 per cent in a length of 10 inches. It could hardly be believed that heat would affect alloyed iron in the same way as it affected pure iron. It might affect iron more that was mechanically mixed with a considerable amount of cinder, but it certainly did not affect ingot

Mr. Adamson. irons free from cinder, and only alloyed with substances that as a rule gave strength and endurance. He referred to such metals as the Siemens-Martin and the Bessemer mild ingot irons, possessing 99$\frac{3}{7}$ of metallic iron, having less alloy than was mentioned in the Tables. The Bessemer metal there illustrated was an ordinary rail metal of moderate good properties, but rather too hard for its purpose. The carbon, he thought, should be reduced $\frac{1}{10}$ per cent. It was represented at 0·4 per cent. If reduced to 0·3, and the manganese to 0·75, the other alloys being as low as could be got consistently with economy of manufacture, a good rail metal would be obtained. If the tests had been such as could be depended upon a very different notion of the carrying power of the metal from its permanent set would be deduced. It was, no doubt, true, as stated, that there was an elongation in 6½ inches of something like 21 per cent. According to his experience, any metal that would elongate in a sectional inch over 12 per cent. in a length of 10 inches would break down, as a condition of its malleability, at a much lower stress than the maximum load that it would carry at another period of the operation; the behaviour of the rail metal was in accordance with its composition. It carried a total maximum load of about 46 tons, and at 50° Fahrenheit it also carried about 46 tons, so that in reality cold produced no injurious effect on it. But he presumed, following the views taken by Mr. Bamber, that as there was an increased crystalline tendency by the abstraction of heat, there would be when starting at lower temperatures, a greater resisting power; and as the work went on, and heat was developed in the material, the metal would arrive at nearly the same extension, and carry an ultimate load quite as large or larger than if tested at a temperature 30° higher. Hence the only influence that, in his opinion, could be produced upon either mild steel or the better class of wrought iron, was that the continued contraction from 32° down to 5° followed the same law as if the tests had been made from 32° upwards in the same proportion. It was true that one could not expect such a result to be established with a piece of cast iron or porous metal of a different composition, because in that case the composition was more seriously affected by cold, than in the case of malleable metals. Pig iron obtained in this country, containing manganese to the extent of 2 per cent., ran freely when molten; it worked well with a cutting tool, but ceased to be practically "fileable." When carrying manganese to an extent of making it Spiegeleisen, it lost its carrying power, it could not be cut, and the hardest drill produced little or no effect upon its surface. Variable compounds

could hardly be expected to possess the same properties and endure in the same ratio, with such a difference in their natural constitution. Every matter connected with mechanical tests should include, in conjunction therewith, a full record of the composition of the metal and its behaviour in standard bars. From what had been said, it might be imagined that a bar of iron had such singular and unmanageable properties that there was neither law nor order about it. It would be a great misfortune if such were the fact. A crystalline appearance and a fibrous appearance might, indeed, partly be obtained at will; but the operations through which the metal was put developed other conditions, and it could not be expected that the same equable appearance would follow when a bar was so differently treated. Taking the case of a billet, 4 inches square rolled down to a ½-inch rod with its particles elongated in one direction, and with cinder interlaced and laid down by the side of those particles, metal so elongated supported a much higher strain when tested in a longitudinal direction; but he was not aware that there was any guide as to how such a bar would retain an approximate power of resistance in a lateral direction, because the batch of cinder that might appear to the eye ⅛-inch in diameter in the larger piece of metal, would probably occupy a length of 2 or 3 inches in the elongated metal. Such must exist, only the elongated metal having thrown off cinder from its surface by having probably exposed from sixty to seventy times the surface originally occupied by the 4-inch bar, a purer iron was obtained, purer from cinder, probably not purer from alloys. How, then, would cold affect a flat bar subject to vibration, when at the same time carrying a moderate tensile load? According to his experience in bursting bars with a drift, it was necessary to increase the area at the end, assuming that a hole was put through the bar, and that it was then drifted with a punch, or a series of punches, advancing 1 in 20; the length of the bar must be increased at the end, to resist the strain that the two side portions should endure, to at least three times the sectional area of the side metal. In other words, if a hole 1 inch in diameter were drilled through a bar 3 inches wide, and then steel pins driven through the hole until the bursting point was reached, both longitudinally and through the narrow section of the side, according to his experience at least three times the metal would be needed in the longitudinal direction to resist the action of the punch that would be required to resist it on the sides, the difference being that the cinder lay chiefly in one direction. He thought that frost would affect such material much more in a Mr. Adamson.

Mr. Adamson. lateral than in a longitudinal direction, as the exposed cinder had power to absorb moisture. He had only once planed an iron rail, to compare it with a steel one, and in that case the streaks of cinder in the longitudinal direction were so manifest as clearly to show that a large portion of the metal was merely glued, as it were, together by the interposed cinder, and had, in large sections of its surface, no metallic contact. Hence the breaking down of the old iron rail when subject to a rolling load must have been expected, if it had been examined closely after planing its upper surface to see how it was constructed. The steel rail, on the other hand, had no cinder; it had no interlaced earthy matter. Hence it endured a heavy rolling load, and did not break down either on one side or the other. Engineers were bound, he thought, to pay great attention to the composition of the metal they desired to use for particular purposes. Mild steel boiler plate and ship plate now in common use contained $\frac{1}{10}$ per cent. of carbon, and $\frac{1}{3}$ per cent. of manganese. If it was desired to get a material of double the carrying power, raised say from 29 tons to 58 tons, it was only necessary to increase the alloying elements about 1·2 per cent., taking care that the quantity of carbon was double the manganese, or say 0·5 of carbon and 1·0 per cent. of manganese. The material would then be one with a carrying power of nearly 60 tons to the square inch, and yet one that could be elongated nearly as much as the best plate iron produced in the country. He thought that, for all practical purposes, as bridge building, steel, especially of the higher malleable class, was the proper material to carry heavy weights with security, because in its longitudinal and in its lateral directions, according to his experience after some hundreds of tests, its strength did not vary more than 2 per cent. Bar iron, on the other hand, did not possess lateral security, but it lost, he felt sure, as much as 66 per cent. of its carrying power if pulled transversely to the grain of the material over some portions of its length in exceptional cases. It was certainly impracticable to pull a $\frac{1}{2}$-inch or a 1-inch square bar transversely through the material, but it was not impracticable to pull transversely a 4-inch or a 6-inch flat bar, and develop all the facts that he had stated as requisite to be known, as a guide in the application of metals to particular purposes at all ordinary temperatures.

Dr. Siemens. Dr. C. W. Siemens observed that the impression produced on his mind by the Paper was that it dealt with a limited question purely for a practical purpose, and that within those limits the results were much as might have been expected. The Author had dealt

Dr. Siemens.

with various metals at the limits of 5° and 50° Fahrenheit. The limit was a narrow one, and it could not be expected that the results of the experiments could be such as would lead to a general conclusion regarding the effect of temperature within wider limits on materials of that description. There could be no doubt that tolerably pure material must be stronger at the lower temperature than at the higher, because the last particles of the material were closer in contact at the lower than at the higher temperature. For a similar reason the material would resist a blow rather less at the lower temperature than at the higher. But he agreed with the observations of previous speakers that no influence was produced by those degrees of temperature on the absolute structure of the metal. It was quite out of the question to expect to change the metal from a crystalline to a fibrous condition, and back again from a fibrous to a crystalline condition, by lowering or raising the temperature a few degrees. The Paper, though valuable of its kind, was suggestive chiefly of what had been omitted to be taken into consideration; for instance, the Author had not in the first instance given a chemical analysis of any of the materials he had employed, though that omission had, he believed, since been remedied; but at any rate he had drawn no conclusion from such analysis. Nor had he considered the elastic limit of the materials, although to an engineer the elastic limit and the condition of the material up to the elastic limit were more important than the breaking strain. Engineers did not want to break down with their materials; but they wanted to see to what extent it was safe to use them. It would have been most interesting if the Author had given the elongation due to the rate of elastic extension at different temperatures. It was Mr. Barlow, the President, who first established by experiments that steel of various tempers was equally strong up to a certain limit. In other words, that if a bar of very mild steel having a sectional area of 1 square inch pure iron, as Mr. Adamson had correctly described it, was weighted with a ton weight, the same absolute extension would ensue as in weighting a bar of very hard steel of 1-inch sectional area and of the same length, and so on, each ton additional weight producing the same amount of extension in both bars until the elastic limit of the mild metal was reached. These results which he must confess at first appeared hardly credible to him, had since been fully confirmed by experiments of his own. It was a remarkable fact for engineers to consider that in constructing a bridge it came to the same thing whether they took mild steel that would break with 28 or

Dr. Siemens. 30 tons strain to the square inch and would come to its elastic limit at about 15 tons, or whether they took a material that would find its elastic limit only at 25 or 30 tons, and would break at 50 or 60 tons; therefore the advantage that would be derived from the hard and strong material would only be met with after exceeding the elastic limit of the milder steel. He was not aware of any experiments giving the influence of heat upon the coefficient of elastic extension of those materials. If it should so happen that a bar of iron or steel at the temperature of 5° would follow a less rate of elastic extension than a warmer bar, a steel bridge that was ordinarily loaded to a strain of 8 tons per square inch, when it cooled down, would contract rather more than in the ratio of simple thermal contraction; and afterwards, if the bridge changed from the one temperature to the other, it would alter its length in all its members due to the two ratios of absolute contraction and a contraction due to a different rate of extensibility. It would be interesting to know how the modulus of elasticity was influenced by temperature. It was often thought that metals were fatigued by strain; and in the case of inferior classes of iron, it might be true that, if a bar were strained a little beyond its elastic limit, its fibres would be ruptured to some extent, and the material would receive an injury; but in the case of high-class material, such as mild steel, there was an absolute advantage in straining it beyond the limit of elasticity. It was possible, by careful manipulation, to raise the breaking strain of a bar of a given sectional area to a remarkable extent by gradually accustoming it to the strain. By taking a bar of mild steel of 1 square inch sectional area and loading with a weight of, say, 15 tons, and leaving the weight on twenty-four hours, it would be found that both the elastic limit and the breaking strength of the bar were materially increased. That was a quality of high-class material which was, perhaps, not yet thoroughly understood, and which certainly gave a great factor of safety in favour of its employment. The chemical analysis, which had not been dealt with in the Paper, was of great importance in reference to the object the Author had in view. The Author had spoken of certain brands of material—of certain makes, for instance by a firm like Krupp's. Now, he happened to know that Krupp made steel by at least three different processes, and it was difficult to say by what process the particular bar was produced that had been referred to in the Paper, nor, if the process were known, could it be affirmed what were the materials used in its manufacture. If it was a cheap material, probably Mr. Krupp would have put in

some cheap iron, and the result might be a bar that would give a very fair absolute strength, but would give way to a bending and breaking test before its time; whereas if he knew that the metal would be tested very severely, he would produce something that would be capable of resisting very high impacts. Some years ago Dr. Siemens made a series of experiments on the power of materials of particular composition to resist blows at different temperatures. His object was to see what effect phosphorus had on mild steel with regard to that quality. From those experiments he had arrived at the conclusion that the power to resist blows in mild steel, at any rate, was dependent almost entirely on the presence or absence of phosphorus. It was well known that phosphorus might be counteracted in the steel, to a great extent, by the addition of manganese; but let the steel be cooled down to freezing point, or below, and the metal would break short: whereas true mild steel, containing only traces of phosphorus and of manganese, would be affected to a very slight extent by any depression of temperature to which it might be subjected. He believed that pure metal was influenced very little by changes of temperature, whereas metal containing foreign matters, and particularly phosphorus, would be influenced to a great extent. It would, therefore, be erroneous to draw general conclusions from such experiments as were given in the Paper. The Author seemed to have attempted to find out results without the chemist; but the chemist now-a-days would put his finger into everything. If they called a thing iron, he would call it a mixture of iron, phosphorus, sulphur, silicon, carbon, and other earthy materials, and it was useless to try to do without him. They must work hand in hand with him in order to arrive at such results as would guide them safely in their practice. Dr. Siemens.

Prof. A. B. W. Kennedy desired to bear witness to the great trouble which the Author must have taken, not only in making the experiments, but in preparing the means for making them; and he was the more sorry on that account that the results obtained did not appear to be, qualitatively at any rate, of any great value. The small percentage of difference with reference to tensile strength (page 176), Prof. Kennedy thought should be discarded, as being quite within the irregularities of such experiments, so that the results might be regarded as practically identical. But in the matter of impact especially, where the Author found the greatest difference, he agreed with Mr. Longridge that the results were hardly given in a form that was fair. In regard to the five Prof. Kennedy.

Prof. Kennedy. experiments made on impact with wrought iron, it might be observed in the first place that the experiments were begun at a great number of different falls, 4 feet, 3 feet, 5 feet, &c., and then the average deflections were measured in the way Mr. Longridge had mentioned, simply by taking an arithmetical mean of the deflections to the last fall before fracture. It was quite a different thing, however, to let a weight fall from a height of 4 feet 6 inches on a bar and break it off, and to let the weight first fall from a height of 1 foot, then from 2 feet, then from 3 feet, and so on. The results in such a case could hardly be compared. It was impossible, for instance, to compare bar No. 1, which had received a blow with a fall from 4 feet, and then a fall from 4 feet 6 inches, with bar No. 3, which began with the weight falling through 3 feet, and went up by 6 inches at a time to 6 feet. In some other cases, the difference was even more marked. In one case of malleable cast iron, the fall began at 1 foot, and in a number of other cases it began at 4 feet. He had worked out the following results:—in the wrought-iron bars, the average deflection at 5 feet, if the first fall was 5 feet or 4 feet, was 0·49 inch; the average deflection at 5 feet, if the fall began at 1 or 2 feet, was 0·62 inch. With steel bars (Table VII.), the average deflection at 4 feet, where 4 feet was the first fall, was 0·07 inch; the average deflection at 4 feet, when the experiments began at 1 foot or 2 feet, was 0·13 inch. He did not think that those quantities were comparable, or that an average could fairly be taken from them. To show how discrepant the results were, it was only necessary to refer to Table VIII. If here the Author, instead of having six specimens at each temperature, had had only five, and if in one group No. 5 had been left out, and in the other No. 11, the result calculated in the same manner as in the Paper would be—average ultimate fall warm, 6 feet 6 inches; cold, 7 feet 10½ inches; and average ultimate deflection warm, 0·38 inch; cold, 0·55 inch; results entirely opposed to those given in the Table. It was really very much a matter of chance in what way the average came out, so that he feared the experiments could not show much as to actual results. As to the question of heat during testing, he had not personally experimented with reference to the point mentioned by Dr. Siemens, but he should be happy to bring forward one or two results as to the difference made by temperatures in the modulus of elasticity. There was one point, however, with regard to heat during testing which was hardly sufficiently remembered—that in its first or elastic stage, when a bar of iron was stretched, it cooled if left to itself. The converse proposition was tolerably

well known, that if a piece of india-rubber was stretched, and put to any sensitive part of the skin, as it was extended a rise of temperature would be distinctly felt, india-rubber being a material that contracted when heated. The converse action took place, as explained in books on physics, with a piece of iron, or any material which expanded when its temperature was raised. He had recently made a number of experiments with a view of examining this action. He had placed a small thermopile in front of the bar tested, and then read off the alteration of temperature by the aid of a reflecting galvanometer, the result being that up to the limit of elasticity there was always a small fall of temperature when the load was put on, and a small rise when the load was removed. He had done the same thing with an air-thermometer, but the results were so small that they could not be measured with the means at his disposal. Prof. Kennedy.

He had made some experiments as to whether moderate changes of temperature measurably affected the modulus of elasticity, and if so to what extent. He used for the purpose a round bar of Landore "S" steel (carbon 0·18 per cent.), turned down to a sectional area of 0·2 square inch, and ascertained the extensions between two points on the bar 54 inches apart. For measuring the extensions he had used the mirror apparatus alluded to by Mr. Webster, which had been described in "Engineering" some months ago, and which measured with accuracy quantities as small as $\frac{1}{10000}$ inch. Between the 54-inch points the bar was enclosed in a piece of 1-inch brass tube, made watertight at each end by india-rubber packing. This tube was encased in wood to reduce radiation as much as possible, and means were provided for running a current of hot or cold water or brine through it. The temperature of the water was measured by a thermometer placed in a short branch at the centre of the tube. Two sets of experiments were made, as given in Tables I. and II. (see next page). In the first experiments (Table I.) the piece was loaded successively with weights amounting to 5000, 10,000, 15,000, 20,000, 25,000, and 30,000 lbs. per square inch, the extension being noted at each load, and the temperature as often as was necessary during the experiment. From the observed extensions at these loads the modulus of elasticity (E.) was calculated in each case, and it would be seen from the Table that a distinct, although small, decrease occurred in it with the rise of temperature. The only special difficulty in making the determinations arose from the necessity of keeping the temperature constant during each. Even a small change of temperature during

Prof. Kennedy.

TABLE I.

Series.	Number of Experiments in each Series.	Highest and Lowest Temperatures, Fahrenheit, used in the Series.	Mean Temperature, Fahrenheit.	Mean Change of Temperature, Fahrenheit, during each Experiment.	Mean Extension per 1,000 lbs. per Square Inch.		Modulus of Elasticity. E.		Increase or Decrease of Extensibility as Compared with Extensibility at 60° Fahrenheit.
					On Whole Length 54 Ins.	Reduced to 10 Inches Length.	Pounds per Square Inch.	Tons per Square Inch.	
		° °	°	°	$\frac{1}{1000}$ inch.				
A	11	37·5– 48·0	41·5	+0·04	1·610	0·298	33,550,000	14,980	1·0 per cent. decrease.
B	9	57·0– 64·5	60·3	..	1·625	0·301	33,220,000	14,830	
C	5	168·0–180·0	175·0	+0·25	1·653	0·306	32,680,000	14,590	1·7 per cent. increase.
D	5	200·0–201·0	200·6	–0·36	1·674	0·310	32,250,000	14,400	3·0 per cent. increase.

any experiment affected all the readings—independently of the particular temperature which was changed—and in some instances sufficiently to disguise altogether their results. Out of forty-three experiments, he had rejected all those in which the change of temperature during the experiment exceeded 1° Centigrade, and he had given in the Table the average change of temperature in the thirty remaining ones, which was slight.

The second set of experiments (Table II.) was made to compare

TABLE II.

Series.	Number of Double Experiments in each Series.	Highest and Lowest Temperatures, Fahrenheit, used in the Series.	Mean Temperature, Fahrenheit.	Mean Change of Temperature during each Experiment.	Mean Extension under a Load of 30,000 lbs. per Square Inch.	
					In 54 Inches.	Reduced to 10 Inches.
		° °	°	°	$\frac{1}{1000}$ Inch.	
E	12	41– 55	48·2	0·0	48·00	8·88
F	15	185–196	0·191	+0·32	48·94	9·06

the extension of the bar at or near its limit of elasticity at different temperatures. In each experiment readings were taken first at zero, then with a load amounting to 30,000 lbs. per square inch, and lastly again at zero. The final reading was seldom exactly the same as the first, on account of small variations of

temperature, but to eliminate any errors arising from this cause, the extensions given in the Table were those corresponding to a zero which represented in each case the mean between the initial and the final length of the bar. The average difference between these two lengths was only $\frac{4}{10000}$ inch (plus or minus), and amounted to as much as $\frac{1}{1000}$ inch only in two cases. Out of thirty-two experiments five were rejected in which the change of temperature during the experiment had exceeded 1° Centigrade, and the Table gave the result of the other twenty-seven. The average change of temperature during these was also given in the Table. Prof. Kennedy.

As a result of the whole, it would be seen that while the extension of the bar under any given load was distinctly greater at high than at low temperatures, the ratio in which the extensibility was increased was comparatively so small that it might safely be neglected for all practical purposes. The experiments had been conducted in the testing machine in the engineering laboratory at University College, and the special arrangements necessary for conducting them were made by Mr. A. E. Ashcroft, Stud. Inst. C.E.

He had no doubt that at the limit of elasticity the material ceased to change its form, even approximately, as it would change it if heated. It behaved as a viscous material, and the expenditure of energy and the change as to heat went on in a different fashion. From other experiments there seemed no doubt that the material began at this point to heat, and heated gradually up to the point where local extension commenced. The Author had pointed out that the material by no means stretched uniformly, even at the place where it did not break. That was quite true, if the final extensions were measured after it had broken, because, of course, there were a number of places where the material was unhomogeneous, and in the weakest places it would stretch a little, but if the process were stopped short of the point where local extension took place, the stretching, at any rate with mild steel or ingot iron, seemed to be practically uniform. He might be permitted to give some results bearing on this point. On a bar of Landore "S" steel, with an area of 0·9 square inch, and a limit of elasticity of 42,000 lbs. per square inch, he put on a somewhat larger load, 49,000 lbs., and on further testing he found that the limit of elasticity was raised to 49,000 lbs. He next put on a load of 58,000 lbs. per square inch, leaving the load on and letting the bar rest afterwards; the limit of elasticity was then raised to 58,000 lbs. The bar was still undergoing test, having borne a

Prof. Kennedy. load of 60,000 lbs. per square inch, and it was still perfectly elastic, that was, at its new length, which was of course much greater than its former one. Its area was reduced to 0·78 square inch, but remained sensibly uniform throughout its length. The same thing had occurred with a piece of Bessemer iron, which he had obtained from Mr. F. W. Webb. The original area was 0·77 square inch; the first limit was 35,000 lbs. per square inch, which by degrees was increased to 62,000 lbs., when the area was reduced to 0·7 square inch, and was sensibly uniform. Between 62,000 lbs. and 64,000 lbs. local extension took place, and the material broke at 65,000 lbs. per square inch. In quoting these figures he had, for simplicity, rounded them off to even thousands of pounds. He therefore thought the better class of materials, at least, remained uniform in section up to within a small distance of their breaking load, if treated in the way described. He was glad to hear the view advocated by Dr. Siemens, Mr. Adamson and others, that what they wanted to know was what the material would do when they could use it, not when they could not use it in connection with the importance of observations made at its limit of elasticity. He would take the opportunity of saying that in any investigations of this kind, where additional scientific experiments were required to be carried on, if they fell within the limit of the testing machine in the engineering laboratory at University College, he should be exceedingly happy, as far as his engagements permitted, to put himself at the service of gentlemen desiring to make experiments in connection with papers to be read before the Institution.

Mr. Wentworth Sheilds. Mr. F. Wentworth-Sheilds said it had always appeared to him, in testing iron for practical purposes, that any test in which the iron was planed down to a given size and the skin so removed was fallacious. He had adopted the plan of testing a bar, of whatever size it might be, and reducing the strain upon the sectional area of the bar to so much per square inch. Again, if a plate were tested for tensile strain, a piece would have to be cut out of each plate, and then there were two sides from which the skin had to be cut. In that way the imperfection of the test would of course be half of what it would be if the bar were planed on all four sides. Plates might be tested, with great advantage for practical purposes, especially when the work was in a hurry, by the hammer, by doubling up the plate and straightening it again, or by punching holes along a piece of the plate and trying how near one could punch to the edge without bursting it through; in that way a good practical test could be applied at the works without difficulty.

He had been much struck with the observations of Dr. Siemens as to the increased strength given to steel by straining it to about 15 tons per square inch or within a little of the permanent set. He had heard the statement before, but he had never acted upon it himself nor had he known of anyone else doing so. He hoped that Dr. Siemens would be able to give some reliable rule showing the extent to which this might be carried. Dr. Siemens had also stated that it was not necessary to test iron to its full breaking weight for practical purposes. That was formerly his own opinion, but it had lately been somewhat shaken. There were many cases, for instance, in which high roofs were exposed to the pressure of the wind, and in which other structures were exposed to severe and unexpected strains—sometimes by loads moving at high velocities, where the iron was strained nearly to its full extent. Many years ago, when resident engineer of the Crystal Palace, it was his duty to make a number of calculations upon the strain to which the roof of that building, especially the great transept, was subjected; and the extreme pressure of the wind was taken at 30 lbs. per square foot. Quite recently he had been called upon to calculate the overturning strain from the pressure of the wind on a high iron viaduct, in order to determine the advisability of taking precautionary measures, and he found by calculation that, with a pressure of 50 lbs. to the square foot, the viaduct would overturn. He had formerly believed that in this country the wind never got up to as high as 40 lbs. pressure per square foot, but he had ascertained that sometimes it exceeded that pressure. He was therefore inclined to dissent from the principle that the ultimate strength of iron should not be taken into account in such structures. Mr. Wentworth-Sheilds.

Mr. J. N. Shoolbred desired to draw attention to a series of interesting experiments as to the effect of temperature on iron rails, which took place some time ago in France and Germany;[1] especially as they supplied some of the information which Mr. Douglas Fox had said was still wanting. The experiments were carried on mainly by the Paris and Mediterranean Company, the Eastern of France, and also by the large rail-making works at Creuzot. They were conducted at different degrees of temperature, ranging from 18° Fahrenheit in winter to 115° in summer. In the trials by impact, the fall, with the same weight, required to rupture the rails differed in some cases con- Mr. Shoolbred.

[1] *Vide* "Voie, Matériel roulant, et exploitation technique des Chemins de fer," par C. Couche, 1867, tome i., chap. 2.

Mr. Shoolbred. siderably; extending from 4 feet 3 inches in winter to more than 12 feet in summer. The diverse behaviour of the rails on different occasions was so well recognised that the test required by the Paris and Mediterranean Company in the specification was altered according as it might take place in winter or in summer. Below 32°, with a weight of 4 cwt., a fall of only 4 feet 3 inches was required, but between 32° and 68° the fall was increased to 5 feet, and above 68° it was further augmented to 5 feet 7 inches. There was a great difference in the tests by falling weight required on English lines and those used on the Continent. Not only was the fall much greater in the former case, but the weight itself was considerably greater; and the bending moment produced by the fall was nearly three times what it was in the Continental requirements.[1]

Mr. Cowper. Mr. E. A. Cowper could state advisedly that iron took a very slight permanent set much earlier than was generally supposed. It used to be thought that iron did not set as a rule earlier than at 10 tons pressure or tension per square inch; but by means of a little instrument he had used many years ago, he had proved that most irons would set at 8 tons tension. It was important in all structures to make them of a permanent character, and of such a strength that they would not alter their shape by any ordinary strain coming upon them. In proving to twice the weight to which they were commonly subjected they ought to be still well within the elastic limit; and having that object in view, it was necessary to ascertain what the elastic limit was. He need only refer to a common experiment. By putting one end of a piece of copper wire a couple of yards in length in a vice, it might be stretched with a pair of pincers 3 or 4 inches without being broken or injured, and it would then carry more than it would before without altering its length. It was soft, perhaps, at first; but when stretched 3 or 4 inches it became harder and capable of resisting a greater strain without altering in length. It had been shown that iron did the same thing to some extent. An experiment had been tried with a bar 7 feet 6 inches long, 5 inches wide, and 1 inch thick. When stretched $\frac{1}{8}$ inch it went back to its original length; when stretched $\frac{1}{2}$ inch it went back about $\frac{1}{8}$ inch; when stretched 1 inch it still went back nearly $\frac{1}{8}$ inch, and so throughout the whole $3\frac{5}{8}$ inches to which it was stretched, having some elasticity at the

[1] *Vide* "Permanent Way Rolling Stock," by Ch. Couche. Translated by J. N. Shoolbred, vol. i., p. 540.

last. To ascertain the point at which iron or any other material first began to stretch, a small instrument was made, 4 feet long. There was a fine vernier, the length of which was one-tenth of the total length of the bar, and it was so divided as to enable one to read the $\frac{1}{10000}$ of the total length. When the bar was strained at 7 tons it came back perfectly, and also at 7½ tons; but just as the strain touched 8 tons it began to be visible that it did not come back. The instrument was used in testing the links employed in the construction of the Kieff bridge, and it was found very useful for that purpose. Such an Extensometer would be much more delicate than the usual means adopted. He thought it was very liberal of Professor Kennedy to offer to place his testing machine at the disposal of the members of the Institution for scientific investigations. It was capable of recording a strain of 100,000 lbs.; and it would be very valuable for scientific experiments. Mr. Cowper.

Mr. J. J. Webster, in reply, observed that one or two interesting points in the Paper had not been referred to in the discussion. One was the value of the reduction of area of a bar when tested, as a measure of its quality; another was the question of the best gauge to adopt in measuring the extensions, he having recommended 6¼ inches; and another was the peculiar form of fracture which took place when steel bars were broken by impact. He had been asked, if, when he measured the 6¼ inches on the bars to be tested at the low temperature, the bar was at the low or the ordinary temperature. He measured all the bars at the ordinary temperature, and although by so doing the length would not be exactly 6¼ inches during the test, yet the difference was so small that it could hardly be appreciated, and could not be measured with the apparatus at his disposal. Mr. Lowthian Bell had said that it had yet to be proved that fibre existed in iron; and Mr. Edward Williams went further, and said that there was no such thing as fibre in iron. Mr. Bell had argued that the fibrous fracture which appeared when a bar was nicked on the top edge and broken in the ordinary way, was caused by the particles being drawn out. The fact, however, of the particles being drawn out, showed clearly that the ultimate particles were capable of being put into parallel lines, or what were commonly called fibres; and it was not necessary to apply a heavy tensile strain to produce this formation, as it was no doubt done in passing the iron through the rolls. If there were no such thing as fibre in iron, plates and bars would have equal strength whether tested with or against the grain; but it was known from experiments Mr. Webster

Mr. Webster. that the results obtained were very different, in some cases being as much as 20 per cent. He had seen hundreds of such experiments, and in most specifications for bridgework the tests for the iron with and against the fibre were given. He had with him a portion of plate, one half of which had been bent across the fibre and showed no signs of fracture; but the other half, being bent with the fibre, was broken across. Mr. Bell, in referring to the statement of Mr. Brunel, quoted in the Paper, that a bar of iron could be broken alternately with a fibrous and crystalline fracture with the temperature, had said he would go further, and say that the same result could be obtained without the application of heat. Mr. Webster had broken a bar as suggested, and he had with him one of the pieces, which showed, as he expected, the alternate fibrous and crystalline fracture; but this crystalline structure did not prove that there was no fibre in iron, for the structure of the iron could be altered in many ways. Mr. Douglas Fox had mentioned that a large number of steel tires had broken in Canada during the severe frosts there, but that none of the solid cast-iron wheels had done so. If this was given as a proof that cast iron was not affected by frost, Mr. Webster could not agree with him, as it was not necessary for a thing to break in order to show that it was affected; and the comparison could not be fairly made with the steel tires, because they might have been broken from causes mentioned in the Paper—unequal and restrained contraction, or hardness of the road. Mr. Fox had stated that the bars tested were not sufficient in number, and that the range of temperature was too limited. The Paper, however, was not intended to be conclusive on all points; it only professed to give a certain amount of evidence. It would require a very large number of experiments to settle the whole question, and it could hardly be expected that the labour should devolve upon one individual. With regard to the alleged insufficiency of the range of temperature, if he had experimented on higher temperatures—which was never his intention, as elaborate investigations had been already made by Fairbairn, Styffe and others—a new series of experiments would have been required; and he considered that 5° was sufficiently low, as it fairly represented the greatest cold experienced in this country. The experiments of Styffe were carried out at a very low temperature, 30° below zero, and their conclusions to a certain extent agreed. Mr. Longridge had objected to his plan of taking the averages, and having worked out some of the averages according to a plan of his own, obtained some remarkable results, which were at variance with those

obtained by him. These results, however, were entirely fallacious, as they were founded on a misapplication of the term "foot-pound." By adding the height of falls on a certain bar, and multiplying by the weight, it was clear that the result could not in any way represent the force of impact on the bar, for the very necessary element, the velocity of the falling weight at the end of its fall, was not taken into consideration. The fallacy of this method could be shown in many ways. Take, for example, the first case in Table VI., where the fall was first 4 feet and then 4 feet 6 inches, after which the bar broke. The sum of these two falls was 8 feet 6 inches, which being multiplied by 40 gave 340 of Mr. Longridge's foot-pounds. Now it was evident, without going into the calculations, that the force of impact of a weight of 40 lbs. falling 8 feet 6 inches was far greater than that developed by the weight falling first 4 feet and then 4 feet 6 inches, even supposing the force of the first blow to be counted as accumulated work, which was scarcely a fair assumption. Again, this number 340 could be made up by having seventeen blows of 6 inches each, multiplied by 40; but it was certain that the bar would never break with such blows, unless repeated perhaps some thousands of times. Mr. Matheson had spoken of the strength of the cast-iron bars being reduced by removing the skin when they were planed. The cast-iron bars, however, were not planed; and even if they had been, it would not have affected the results, as the conditions would have been the same in both sets of experiments, the results being merely comparative. Mr. Matheson had also remarked that the experiments described in the Paper did not account for the fractures which took place at low temperatures with different structures. It was never intended that they should do so, as these fractures doubtless occurred from countless causes; the object of the Paper being to ascertain how the material itself was affected by frost when under certain strains. Professor Kennedy had remarked, that as the percentage of difference obtained in some of the experiments was so small, they ought to be discarded. Mr. Webster could not agree with this; for the experiments showed that there was a difference, and however small it was, to give a true account of the experiment, it should be recorded; and in his summary of the results he had mentioned that for practical purposes it might be neglected. Professor Kennedy also objected to the method adopted for taking the averages. Averages, no doubt, could be taken in many ways, and so twisted as to give curious results; but he thought that the plan proposed by Professor Kennedy was a most unfair one. Mr. Webster.

Mr. Webster. In taking averages, good results must be taken with bad ones, and the more results there were to work upon, the more likely it was that the truth would be arrived at. The plan proposed by Professor Kennedy of taking out a result here and there, because it happened to be higher or lower than the others, was obviously an unfair one. for the number of results was thus reduced, and by repressing any one or more of them, a false average was obtained. As regarded his remarks about the height of fall not being the same at the commencement in all cases, this did not affect the results so seriously as he supposed; but the number of falls on each bar varying so was a difficulty which could not be avoided. If it were possible to ascertain the exact height from which the weight should fall to break a bar, or the exact number of blows required to do so, the results would be more accurate; but as this was an impossibility, the next thing was to break the bar with as few blows as possible. The effect of the falling weight from a 1-foot to a 4-feet fall upon the steel bars was so trifling that they might be said practically to have started from the same height. With reference to the remarks of Dr. Siemens, that no deductions had been drawn from the chemical analyses of the materials, this was outside the scope of the Paper. A chemical analysis was given of all the samples, so that if any member wished to draw any conclusions from them, he had thus an opportunity of doing so. With regard also to the moduli of elasticity of the materials not being given, that was another question which was without the range of the Paper, and would have required a new set of experiments to have investigated it. Dr. Siemens, Mr. Adamson, and Professor Kennedy had remarked that engineers did not wish to know at what strains the materials would break, but how far they could be used without exceeding the limit of elasticity. This opened an important and rather complex question, and much could be said on both sides; but the majority of engineers were decidedly in favour of the breaking strain of the material being adopted as a base upon which calculations should be made when determining the sections required to withstand any given load; and it was upon this base that the requirements of the Board of Trade in bridgework were founded. It was well known that in the commonest iron, the limit of elasticity was often as high, if not higher than that of the best iron, and supposing a bridge to be designed, having its several parts apportioned according to a factor of safety based on the limit of elasticity, it was evident that as this limit might probably be near to the breaking strain of the material, the bridge would not be so strong as anticipated, and

the factor of "safety" would be a misnomer. He was strongly of opinion that the factors of safety adopted in bridgework should be based upon the breaking strains of the materials employed, and not upon their limits of elasticity; although it might be advisable under certain circumstances to specify the latter also. Mr. Webster.

Mr. W. H. Barlow, President, thought the members of the Institution were greatly indebted to the Author for bringing forward a subject of a philosophical character, thus usefully leading their minds a little off the ordinary track which they were accustomed to pursue. It was perhaps true that the Paper did not take such a wide range as it might have done, but it could not be expected that any individual member should carry such a subject to its extreme limits. They were not only indebted to the Author for his Paper, but for the excellent discussion which had arisen from it, and the valuable information contained in the remarks of Mr. Adamson, Dr. Siemens, Mr. Longridge, and Prof. Kennedy. He desired especially to refer to Prof. Kennedy's offer to place his testing machine, when he could do so without disturbing the ordinary course of his avocations, at the disposal of the Institution. He had no doubt that the offer would be gladly accepted by the members, and that the result would be a great addition to their knowledge with reference to such subjects. Mr. Barlow

Correspondence.

Mr. W. Anderson regretted that the chemical composition of the metals experimented on had not been given. It was now generally agreed among metallurgists that by "iron" should be meant pure iron only, and that by "steel" should be meant a combination of iron and carbon only. When those metals contained other substances they ceased to be iron or steel in the strict sense of the terms; their properties became different, and many of the apparent anomalies which had arisen during experiments on metals might be accounted for by the fact that chemically the substances were not the same. Mr. Chernoff had illustrated the importance of this remark in the following communication, in which he showed that the presence of phosphorus made the steel with which it was allied more brittle in cold weather, while pure steel was not affected by cold. The "cast steel," which had been tested, it was presumed, was crucible steel, forged or rolled after casting, and not steel castings. According to Chernoff, steel castings, in the form of steam-hammer heads, seemed to be affected by cold much as cast iron had been shown to be. Mr. Anderson.

Mr Chernoff. Mr. D. CHERNOFF, through Mr. W. Anderson, doubted if there existed records of systematic experiments on the influence of frost on the strength of iron and steel in Russia, but he had a few facts which related to the question. It had been proved that the presence of phosphorus in iron and steel became apparent in frost; the more phosphorus the metal contained the more brittle it was in cold weather. Among others, Mr. Lundicheff communicated the following facts. On the 8th of March, 1875, in the rolling mills of the Chief Society of Russian Railways, at a temperature of $-7°\cdot5$ Centigrade, the following tests were made, by means of falling weights, on rails of phosphoriferous steel. The specimens stood the fall of 648 lbs. from a height of 10 feet, but broke, the pieces flying asunder, when the same weight fell 13 feet. After the experiments the halves of the broken rails were laid aside till the weather should get warmer, and on the 19th of May of the same year, and under the same apparatus, at a temperature of $+12°\cdot5$ Centigrade, the tests were repeated. After two blows from a weight of 1,152 lbs., falling 10 feet, and one blow from the same load, falling 15 feet, the rails were bent to an angle of 120°. A weight of 2,232 lbs. was then dropped from a height of 15 feet 4 inches, when the rail did not break, but was bent to an angle of 100°. The presence of phosphorus was recognised as injurious by the Ministry of Ways and Communications, and special rules had been laid down by the Ministry for testing for phosphorus. It was absolutely necessary, in receiving rails for service, that they should be tested by bending in special localities where an artificial temperature of $-12°\cdot5$ Centigrade had been produced. At the Abouchoff works, with good materials, tires, whether made of Bessemer, Siemens-Martin, or crucible steel, were tested under falling weights in winter. In 1879, for example, one of the deliveries of tires took place at a temperature of $-19°$ Centigrade, yet all the specimens selected stood the required test.

He had often observed that, during winter, breakages took place most frequently immediately after the works had been standing idle during holidays. These fractures occurred especially to the hammer heads and anvils of the steam-hammers, and to the chains of the cranes if these had not been well heated up to about 100° Centigrade. It was now an established rule that in winter the chains of the hammer cranes, and the hammer heads and anvils, should be warmed before work commenced. The hammer heads and anvils of the large steam hammers, especially, [illegible] to be heated for a long time. For example, the heads of [illegible]n hammer, weighing from 8 to 9½ tons, had to be heated

nearly the whole night before the resumption of work, and without this precaution they would infallibly break. He might add that the hammer heads and anvils were made both of steel and of cast iron, and heating was found necessary for both materials. Mr. Chernoff.

Mr. H. Carlile agreed with much that had been advanced by the Author. He thought, however, that a temperature of 5° above zero Fahrenheit was much too mild to give any very decided experimental results, and would rather propose that the experiments should be extended to such temperatures as 25° and 35° below zero Fahrenheit, when he had no doubt unmistakable results would be arrived at. To show that in Russia it was accepted that steel was rendered brittle by great cold, he begged to quote the following translation of an extract from the last Russian Government rules for testing Bessemer steel railway rails: "Should the delivery of the rails take place at such a season when the temperature is warmer than 10° to 15° below zero (Réaumur), it is indispensable that the two rails which are to be subjected to the blow-test be tested at the lower of the above-mentioned temperatures. The artificial reduction of the temperature will be attained through a mixture of 2 parts by weight of ice and 1 of salt. For this purpose the pieces of rail to be subjected to the refrigerating process are to be laid in wooden boxes 8 feet long, 3 feet wide, and 2 feet deep, half filled beforehand with the aforesaid mixture of ice and salt, and is then to be covered with a like layer of the same mixture. The temperature of the rail will be determined by means of a thermometer inserted in a depression bored in the head of the rail, and filled with quicksilver." Experience of railway traffic in Russia showed that most of the failures in rails, wheel tires, and bearing springs, occurred during hard frost, due, probably, partly to the low temperature, and partly to the rigidity of the permanent way. There were fewer breakages in November and the beginning of December than, with the same degree of cold, in January and February, when the frost had penetrated deeper into the ground, and rendered it harder and less elastic. Mr. Carlile.

Mr. H. D. Furness would confine his remarks to experience gained on three railways in Northern and Central Russia, extending over a period of nine years as Locomotive Superintendent. In the first place he must take exception to the remark (page 161), "that in those countries where the winters are longer and more severe than in Great Britain, no such records of fractures are kept." He could safely say that in Russia returns were kept Mr. Furness.

Mr. Furness. that would bear favourable comparison with those of any country. In fact, the history of every axle, wheel, and tire was noted and duly registered. 1st. The mileage done every month, and the total mileage at the end of such month by each of the above. 2nd. The fractures that had occurred to each, with the date. 3rd. The repairs done and the nature of the repairs. This was all recorded so accurately, that he was sure that anyone examining the books in the Locomotive Superintendent's Office—take, for instance, the Dunaburg and Witepsk railway—would find in the case of, say, axle No. 100, by whom it was made, the date of manufacture, under what wagons it had been, if it had been bent and then straightened, what mileage it had run up to the end of 1879, and the same for the wheels and the tires. The system of doing this was not so difficult as it looked. The method of ascertaining fractures was simply by paying a small premium to those persons finding such fractures. Regarding the fracture of tires, so far as breaking across the tire was concerned through contraction, impact, or other cause, his experience had been that the greatest number of such fractures did not occur in the severe winter months, but generally in those months in which the greatest variation of temperature took place, and from this he always considered that the difference between the expansion of the wheel and tire found out the weak places, the tire always giving way at the weld when of wrought iron, and invariably at the bolt hole in steel. There could be no doubt that the majority of fractures in winter resulted from the hard and frozen state of the track, but this arose from the tires that had been turned up a time or two, which were absolutely drawn out in the transverse section, forming a curve, in some instances $\frac{1}{4}$ inch deep at the centre; thus after they had been considerably drawn out cold by impact on a hard road, they split round the circumference of the tire. From these remarks it would be seen that unless the nature of the fracture were known, not even the Board of Trade statistics could be relied upon to form data as to the effect of low temperature on iron and steel.

Mr. Cuningham. Mr. W. M. Cuningham supplied the following statement (see next page), showing the number of rails broken and deteriorated on a railway in Northern Russia during 1878.

Dr. Hopkinson. Dr. J. Hopkinson observed, that the blow required to break a body by impact should not be proportional to the steady stress required to break it was precisely what should be expected. For the purpose of illustration, suppose a beam supported at its extremities a unit weight hanging at its middle caused deflection a, a weight W would break the beam, the deflection before breaking would be

Mr. Cuningham.

Works.	To 1st Jan. 1879. Length of Rails.	Average life of Rails to 1 Jan. 1879.	In the course of 1878, Broken and Removed Rails.		Temperature (Reaumur) in 1878 ranged from — per Month.	Month.	Steel Rails.				Iron Rails.		Totals.
			Pieces.	Percentage of Versts.			English Works, No. 1.	English Works, No. 2.	French Works.	Belgian Works.	Type No. 4.	Type No. 3.	
	Versts.	Years.			° °								
Steel rail, type No. 5, (66 lbs. per yard)—													
English works, No. 1	323·197	0·694	11	0·044	+ 1 to − 20	January .	..	2	1	1	997	986	1,987
,, ,, No. 2	426·189	0·696	14	0·053	+ 2 ,, − 12	February .	1	2	1	..	1,618	954	2,576
French ,, . .	66·327	2·39	31	0·123	+ 8 ,, − 9	March . .	..	6	3	..	1,485	828	2,322
Belgian ,, . .	28·518	3·843	3	0·011	+ 7 ,, − 2	April . .	..	..	2	..	869	495	1,364
Steel rail, type No. 3.					+ 6 ,, + 16	May . .	1	..	1	2	863	392	1,255
English works, No. 3	2·41	11·25	..	..	+ 11 ,, + 21	June . .	..	1	..	..	762	353	1,116
,, ,, No. 2	2·046	12·249	..	..	+ 9 ,, + 19	July . .	1	..	..	..	733	400	1,134
Iron rails, type No. 4.					+ 10 ,, + 16	August .	..	1	6	..	807	424	1,238
Various works . .	433·113	unknown	12,565	34 versts	+ 5 ,, + 13	September	3	..	1	..	805	358	1,163
Iron rails, type No. 3—					+ 10 ,, − 6	October .	..	1	1	..	1,044	715	1,761
Various works . .	370·819	unknown	6,642	18 ,,	+ 4 ,, − 20	November.	3	1	10	..	1,475	372	1,847
Totals . . .	1656·616	..	19,266	52·231	+ 1 ,, − 12	December .	2	..	5	..	1,107	389	1,503

NOTE.—Verst = ⅔ mile. The worst steel rails prove to be those of the French works. The greatest number of breakages of iron rails took place in February and March; of the steel rails 24 per cent. broke in November.

Dr. Hopkinson. a W if the deflection was proportional to the weight, the work done in deflecting the beam till it broke was $\frac{a^2 W}{2}$; if a weight P falling from a height h just sufficed to break the beam, then $h P = \frac{a^2 W}{2}$.

If change of temperature increased W, the load that could be carried by the beam, it by no means followed that it would increase h P, the blow needed to break the beam, for the effect of the change might be to diminish a, or render the beam stiffer, and so render it more liable to break under a blow, although increasing the strength of the material. This illustration was sufficiently trite, but he thought it well to repeat it, as one continually heard expressions of surprise that rupture under steady stress and under impact were not found to vary together.

In most cases the phenomena of rupture under impact were by no means so simple. Passing over the fact that stress and strain were proportional only if they were small, a variety of complicated time-effects ensued. First came the question whether the deformation was effected so rapidly that the change might be considered adiabatic, or whether there was time sufficient for conduction to have a sensible effect in equalising the temperature.

Secondly, the stress in a body at any time depended not only on the strain at that time, but on the strains which had preceded. This subject had been much studied in Germany under the name of "Elastische Nachwirkung." It was probably not of great practical importance to the engineer, but it was intrinsically interesting. Suppose a wire, or better a thread of glass, to be twisted for an hour and released, it would not at once come back to its unstrained state, a small twist remained which slowly diminished and disappeared. The most curious thing was that the thread had the trick of remembering a good deal of its past history. Twist it for an hour in one direction, then for five minutes in the opposite direction, and release it; a small and rapidly decreasing twist remained in the direction of the last twist it received; this soon disappeared, and the effect of the longer previous distortion made itself manifest; the fibre showed a twist in the other direction, which slowly attained a maximum, and then still more slowly decreased to zero.

Thirdly, and he thought this was important, a body might break under impact, the reaction being not against supports but against its own mass. Some years since he investigated the

simplest case of rupture in this way.[1] A wire was hung vertically, stretched by a weight sufficient to keep it straight; a block of cast iron weighing 26 oz. grasped the wire near the bottom firmly, but without danger of cutting; a spherical weight with a hole through it could slide on the wire and drop freely on to the clamping block, so inflicting on the wire a purely tensile blow. Theory showed that if the wire were very long it would break just above the clamp; that if the wire were not very long the fall needed to break it close to the clamp would be the same as if the wire were very long; that correcting for the mass of the clamp the height of fall was the same for all weights. The last rather astonishing result was verified; a ball of 41 lbs. had to fall 5 feet to break the wire at the clamp, whilst a ball of 7¼ lbs. weight accomplished the same with a fall of 6 feet 9 inches; correcting them for loss of velocity due to the inertia of the clamp, the heights obtained were 4 feet 7 inches and 4 feet 6 inches. He then tried cooling the wire just above the clamp with ether, and found that a smaller height of fall was needed to break the wire; an effect in this direction might arise from decrease of tensile strength, from increase of coefficient of elasticity, or from increase of density of the material. Dr. Hopkinson

Dr. J. P. JOULE observed that the conclusions drawn by the Author, from his elaborate experiments on the strength of iron and steel at low temperatures, agreed in the main with those deduced by Mr. Spence and himself from their respective experiments.[2] They all showed that the reduction of strength by exposure to cold, was, if any, so small that, as the Author stated, it might be neglected in the design of structures. Mr. Webster, however, made an exception in the case of cast iron. It appeared to him that the results recorded in Tables III. and IV. did not bear out this exception, inasmuch as they showed almost equal breaking weights for the different temperatures of the cast-iron bars employed. In Table VIII. it appeared to him that the trials were too few to establish any discrepancy. One of the greatest necessities in experiments of this nature was that of securing, as far as possible, the perfect uniformity of temperature in the specimens under trial. On this account among others, he chose "garden nails," the small dimensions of which prevented any great variation of temperature throughout their mass. The like precaution seemed Dr. Joule.

[1] *Vide* Proceedings of the Literary and Philosophical Society of Manchester, vol. xi., 1871–72, pp. 40, 119.

[2] *Ibid.*, vol. x., p. 91.

Dr. Joule. to have been employed by Knut Styffe, whose experiments appeared satisfactory in all respects.

Mr. Millar. Mr. W. J. MILLAR was much interested with those parts of the Paper referring to the strength of cast iron at low temperatures, and the peculiar curved fractures of the steel bars, as he had made some experiments of a like character. One point, however, must be borne in mind, viz., that to get reliable data from experiments on cast iron, a large number of tests were required. This arose from the great variation in the strength of the test bars. Even when such bars had been cast from the same running, it was not unusual to get a high result from one of the bars, whilst a neighbour broke at a comparatively low strain, yet both bars would show perfect soundness, no apparent difference being observed in the fractured surfaces. On a comparison of the bars of high and low temperature given in Table IV. of the Paper, it would be found that the highest strength was shown by No. 11 bar, of the low-temperature series, and if bar No. 8 were kept out, as it was exceptionally low in strength for such span and section, the average of the remaining four bars was 29 cwt., with a deflection of 0·275 inch. Comparing this average with the average of the highest four bars of the higher-temperature series, the result was 29·15 cwt., with a deflection of 0·31 inch, the values of the breaking strength being practically the same in both cases. There appeared, however, a slight decrease of deflection in the bars subjected to cold. Lately, whilst testing some bars, three were exposed to the action of cold by being buried in snow; the average transverse strength of these was 3,133 lbs., with a deflection of 0·372 inch, whilst the three companion bars not subjected to cold gave 3,055 lbs., with a deflection of 0·400 inch as an average. There appeared also in this case a decrease of deflection for the cooled bars.

In respect to the peculiar curved wedge-shape fractures in steel bars, this form of fracture was said by some writers to occur in cast-iron bars, but although he had tested several thousand bars, not a single case of such a form of fracture had been observed. It appeared, however, to occur in steel bars, as observed by the Author, by Mr. Kirkaldy, and by others. The curves when met with in cast-iron bars were of the annexed form (Figs. 9, 10, 11), and the two pieces always fitted together. He had found that such curves invariably occurred when the fracture had commenced at a point removed from the centre of the span, and pointed towards the point of application of the load. When rupture occurred at or near the centre of the span, the fracture was

straight. The position of the fracture could therefore be de- Mr. Millar.
termined by the form it assumed. Similar shaped fractures were got when experimenting with glass and sealing-wax bars, and these followed the same law as he had found to apply to the

Glass Bars.

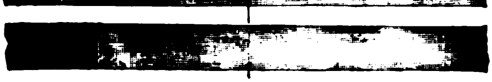
FIG. 2.

FIG. 3.

FIG. 4.

FIG. 5.

FIG. 6.



Sealing Wax Bars.

FIG. 7.

FIG. 8.

Cast-Iron Bars.

FIG. 9.

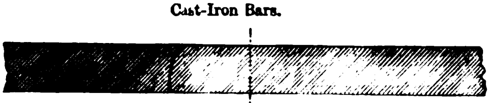
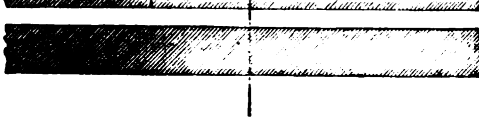


FIG. 10.

FIG. 11.



Steel Bar.

FIG. 12.

cast-iron bars. He believed that the formation of such curves was due to the unequal length of the two pieces of the bar, the larger piece on straightening diverting the upward line of the fiacture. The form could have no reference to the position of the neutral layer before fracture, as, immediately on rupture commencing, the

Mr. Millar. position of the neutral layer would be altered. The glass bars (Figs. 2, 3, 4, 5, and 6), indicated very fine curved fractures, but it could be shown by the action of polarised light that the neutral layer lay at the centre of the depth, even when the piece was strained to the breaking point. In the case of a steel bar broken by impact (Fig. 12), the fracture was similar to that obtained in the cast-iron bars so that the wedge-shape form of fracture did not always hold in steel. The probable explanation of the wedge-shape form might be that where it existed, a broad surface had been used for applying the load, and not a narrow edge, as usual. The load being distributed over a short distance, as appeared likely from the size of the falling weight used by the Author, the tendency would be for the fracture to run in the direction of D or E (Fig. 1, p. 175), that is to say, towards the points of the span where bending might be said to commence. It would be interesting to have exact outlines of the forms of the curves, and to know if the line of fracture lying below C (Fig. 1) was at the centre of the span or to one side of it, as he had been handed by a friend a sketch of some fractures of steel bars, in which the wedge-shaped part appeared to have occurred at the lower or tension side. The rounding of the fractured parts at A D and E B (Fig. 1, p. 175), was similar to that in the sealing-wax bars (Figs. 7 and 8).

The experiments by the Author upon the transverse strength of bars under impact were very interesting; the height, however, of fall given for the cast-iron bars seemed small. In some experiments which he had made in this direction, bars of similar section and span had been subjected to a weight of 13 lbs., falling from heights up to 6 feet, but had remained unbroken after repeated blows. With an 18-inch span one bar stood five blows, and remained unbroken up to a fall of 6 feet. Another bar of the same span broke at the second blow, with a fall of 5 feet. A bar of 36 inches span stood seven blows of a 27½-lb. weight falling from varying heights; the eighth blow from a height of 6 feet broke it. The companion bar cast along with this one broke at 4,000 lbs. of a transverse load gradually applied, and showed an ultimate deflection of 0·418 inch.

Mr. Lightfoot. Mr. T. B. Lightfoot said Messrs. J. and E. Hall had at their works at Dartford a cold air machine capable of reducing the temperature to about 50° below zero Fahrenheit. He had much pleasure in offering the use of the machine to any members who might desire to experiment upon the behaviour of materials at low temperatures. The only difficulty was that they had no testing

machine, though for such purposes as impact some contrivance could easily be made. The machine, as at present arranged, discharged into a wooden chamber. The use of the plant would, of course, have to be obtained by previous arrangement. Mr. Lightfoot.

Mr. J. PARFITT remarked that iron and steel rails, if of good quality, would stand the same test both in summer and in winter, the only difference being that the amount of deflection of the rails was somewhat less in winter; but if the metal was of inferior quality, rails which would endure a certain test in summer would, with a few exceptions, break under a similar test in winter. Mr. Parfitt.

Mr. JAS. PATERSON observed that wrought iron, when subjected to a tensile strain, appeared to be very slightly altered by change of temperature, the ratio being as 1 to 1·007 in favour of the higher temperature. Mr. Kirkaldy in his researches on the strength of iron, found that a $\frac{3}{4}$-inch bar tested at 64° Fahrenheit was ruptured at 24·87 tons per square inch, while another portion of the same bar tested at a temperature of 23° Fahrenheit broke under a strain of 24·28 tons, being in the ratio of 1 to 1·024 in favour of the higher temperature. In the case of steel the tensile strain was increased under the lower temperature to the extent of 1·004 to 1. The generally accepted opinion hitherto had been that the compression of wrought iron by hammering increased its tensile strength, and reduced its elongating properties, but this view was not supported by the Author in his experiments on iron. Whether the increase in the tensile strength of steel was due to increased compression through the influence of cold, or whether from some difference in the molecular structure of the steel, was uncertain. In the case of cast iron, the transverse strength did not appear to be greatly altered, being reduced under the lower temperature in the ratio of 1 to 1·028 or 2·8 per cent. When subjected to impact the conditions seemed to be seriously altered. Taking the average height of fall for the low temperature at 1, and the height of fall at the higher temperature as 1·36, the ratio was 1 to 1·5 against the low temperature. Not improbably the molecular state of the iron would be equally altered through the influence of cold when placed under the respective tests; but in the transverse strain, the pressure being applied gradually might probably tend to liberate the latent heat of the bar and raise the temperature at the point of compression. His experience of cast-iron girders fixed to the supporting columns of gasholders rather favoured this supposition. In the case of one erected a few years ago, having a diameter of 97 feet, supported by ten cast-iron columns and girders, the trough guides being also of cast iron, Mr. Paterson.

Mr. Paterson. fixed to the columns in the usual way, 6 feet apart from centre to centre, three of the guides gave way during the severe frost in January 1879; and a similar casualty occurred during the severity of the frost early in the following December, when three guides again gave way and threw the gasholder out of position. Two of the broken guides had since been tested, and one of those not broken. The bearings were placed 5 feet apart from centre to centre, temperature 60°. The first broken guide was fractured at a pressure of 2 tons 18¾ cwt., the ultimate deflection being ½ inch. The second, placed under similar conditions, gave way at a pressure of 2 tons 10 cwt., the ultimate deflection being ⅜ inch. The unbroken guide gave way under a pressure of 3 tons 5¼ cwt., the ultimate deflection being $\frac{9}{16}$ inch. It was highly probable that the weakest guide first gave way, and that the impulse communicated by the weight of the gasholder ultimately broke the two adjoining to the right and left. They had now been replaced by others of wrought iron.

Mr. Pihl. Mr. Carl Pihl, of Christiania, had made inquiries respecting the behaviour of iron and steel when exposed to extreme cold in Norway. Mr. Sinclair, who had been engaged twenty-eight years as superintendent of permanent way on the Kongsvinger railway, a line of 70 miles' length, and exposed to extremely low temperatures, had informed him that only one iron rail had been broken in the course of fifteen years, and one steel rail during the last four years in which steel rails had been in use. The iron rail broke more from accident; the steel rail from imperfection in the manufacture. The rails wore away much more during winter than summer, in consequence of the very hard frozen road, the frost penetrating from 4 to 6 feet below the rail. Axles, tires, and springs were broken more during winter than summer; but this he also considered to be caused by the hardness and unevenness of the road, and by the heavier traffic in winter than in summer, and not from low temperature. In bridges he found no difference. He thus concluded: 'In my opinion the only difference between summer and winter in damage to road and rolling-stock lays alone in the hardness and unevenness of road." The temperature experienced on the railway in question had yearly been − 22° to − 35° Fahrenheit. The extreme cold, however, did not last more than three or four days at a time. Three or four times, however, the temperature had been so low as to freeze quicksilver, consequently at − 40° Fahrenheit.

The next report he had received was from Mr. Mellbyo, engineer and traffic manager of the southern portion of the Hamar-Dron-

theim railway of 3 feet 6 inches gauge, 269 miles long, crossing the Dovrefjeld in N. latitude 62° 30′ at Róros copper-mines, at an elevation of 2,200 feet above the sea. He mentioned two instances of locomotive steel tires springing, one 2 inches thick at a temperature of 18° Fahrenheit, the other 1 inch thick at – 15° Fahrenheit. No iron tires had sprung, and only one stock rail sprung, in several pieces, when a locomotive passed over it, at a temperature of – 4° Fahrenheit. The lowest temperature generally reached was from – 30° to – 40° Fahrenheit, that being the extreme cold in Norway. From this it might be inferred that the breakages mentioned were caused, as in the former instances, rather from the hard and uneven road than from the effect of low temperature, the road getting very uneven by being lifted by the frost, sometimes to the extent of 18 inches above the ordinary level. Mr. Pihl.

Though the above observations and opinions were not derived from direct experiments, and though they gave no conclusive evidence, yet he trusted that, as the results of many years' experience, they would be of some practical interest.

Finally, he had received a report, from which the same conclusions might be drawn, from Mr. Krefting, the engineer and traffic manager of the Christiania-Drammen-Randsfjord narrow-gauge railway, together with its branches 111 miles long, and having 40-lbs. steel and iron rails.

As an illustration of the effect of want of elasticity in the road on the rolling-stock, Mr. Pihl mentioned that some years ago he had introduced india-rubber pads between the axle-boxes and springs, which had effected a reduction of $\frac{2}{3}$ or $\frac{3}{4}$ in the turning of the wheel-tires from what had been necessary during the previous winter.

Mr. C. P. Sandberg, having been largely employed for twenty years by Scandinavia, Russia, and Canada, as inspector of rails, the subject was naturally of great interest to him. At the instigation of the Swedish Government he had been requested, ten years ago, to make some experiments, of which the Author had quoted an abstract in the Paper, along with those of Styffe and Fairbairn. It was gratifying to find a private individual devoting so much time and cost in trying to solve a question, for which the above-named countries, in colder climates, would be greater gainers than England with its comparatively mild climate. It was surprising that so little had been done in the way of experiment by these countries. The Swedish Government had instituted the experiments made by Styffe and his colleagues, and had paid all their Mr. Sandberg.

Mr. Sandberg. expenses, but he was not aware that either Russia or Canada had done anything of the sort. The wide range of the subject, if it should be thoroughly investigated so as to be of practical utility, demanded more time and cost than could be expected from any private individual; but any such work done deserved high praise, however small it might be: and in this respect he could not agree with Dr. Siemens, that the information in the Paper was deficient. The Author was wrong in supposing that Mr. Sandberg had compared the results obtained from long rails with those of half lengths. The results were taken by comparing the strength against impact of ten rails, all in halves, tested one half at 10°, the other at 84°, although he admitted that the Table included also the results of long rails tested for impact; but they were not taken into comparison, as was explained in the few lines after the Tables, and before the conclusions were given.[1] He thought there was but one opinion as to cold affecting the strength against impact of those classes of iron and steel which contained certain impurities, called hardening substances, such as phosphorus, carbon, silicon, and even manganese; and this should not be a matter of doubt considering the well-known term of cold short iron. This term had not been applied to steel because formerly steel was only made from pure material, such as Swedish iron melted in crucibles. With the introduction of the Bessemer and Siemens processes for the manufacture of large quantities of cheap steel, and the application of Thomas and Gilchrist's process in the Bessemer, and the production of the so-called phosphor steel by the Siemens process, he feared the public would be as familiar before many years with the expression of "cold short steel," as they were now with that of "cold short iron." Taking a broad view both of the Paper and of the discussion, there seemed to be a want of practical ability. For instance, speaking of testing, as a practical man he would make a distinction between scientific tests for discoveries of the nature of the material, and such as were applied in practice, although the former were of great value, and must form the basis of rules for the latter. He thought progress was much retarded by not working the former on a larger scale, and in a more practical way, than had been done by experimentalists. For instance, testing the materials used for a certain purpose should be as nearly as possible effected in the same way as it would be in practice. The test should be simple, require no expensive

[1] *Vide* "Iron and Steel," by Knut Styffe. Translated by C. P. Sandberg. Appendix, pp. 156 and 157.

machinery, cost little, and above all be speedy. What engineers Mr. Sandberg. aimed at was of course to get a sufficiently good, strong and safe article at the cheapest price; any overdoing in this respect would always be a loss, although it was better to be on the safe side. He held that the materials, iron and steel, should be tested by impact in all cases where the articles would be subjected to it in practice; when the articles were to be subjected only to dead loads, the testing of elasticity and tensile strength would be sufficient; and here it was that most of the faults lay. For instance, a rail should be submitted to concussion; for when a train ran over it at high speed, it suffered more from concussion or impact than from wearing effects. He could not conceive it to be right that the German engineers, in their steel rail specifications, only included the test for tensile strength but no falling test. The former test he thought would be better applied to boiler plates than to rails, as they were both slow and costly and not to the point; for no connection had yet been arrived at between these two tests and that of impact. It was with this view that he operated upon rails, in testing the effect of cold in Sweden, and he was glad to find that M. Chernoff had adopted the same plan. He was opposed to the application of mechanical tests to the material in smaller dimensions than what were used naturally, for not only was a change incurred in taking the skin off, or otherwise reducing the material to minute dimensions, but any unevenness or non-uniformity would yield misleading results. He preferred large dimensions, even if the arrangements were somewhat crude and rough, and therefore he did not advocate, with Dr. Joule, operating on garden nails. The next point of importance was the number of experiments that could be made quickly, to guide, if possible, the maker in the completion of the manufacture, according to desire; but if that could not be done, it would serve to assort the metal for different purposes. For instance, in the Siemens process, the testing of the steel before it was tapped, so as to obtain the exact degree of hardness wanted, was of the greatest importance and value. In the Bessemer process this method was only applied where the Thomas and Gilchrist process was used; for, by judging of the fracture and blowing, say, another half a minute, success in making strong steel out of pig iron containing 2 to 3 per cent. of phosphorus, entirely depended. Unfortunately the tests that could be applied by inspection of the finished article were much too costly and complicated. Thus, only 1 per cent. of the rails, axles, or girders were tested, and it must be taken for granted that all the others were alike; and this necessitated a surplus of strength,

Mr. Sandberg. so as to be on the safe side. In this respect he thought a conclusion could be drawn on the effect of cold on iron and steel when the material was impure, so that there must be a special material made for cold countries. Here the tests, sufficient for structures in mild climates, would have to be increased, in order to secure safety for similar structures in cold climates. He was therefore of opinion that falling tests for rails intended for Russia should be different to those for England, and that there should be different heights of fall according to the temperature at the time of testing. Rails tested at the place of manufacture, in a mild climate, could not be expected to stand the same blow or impact in a cold country; and it remained to settle the proportion of the height of fall according to the different degrees of cold. He had tested rails in Russia shortly after a cold of 40° Fahrenheit below zero, but it was thawing at the time; still the rails were exceedingly brittle. As mechanical tests gave different results if time were allowed to act, so it seemed also that this was the case of the effect of cold. In fact, the metal had a tendency to regain its former condition to a certain extent if only sufficient time was given.

Dr. Siemens had pointed out the value of chemical tests in conjunction with mechanical, and in this Mr. Sandberg concurred; but more as an explanation of the mechanical conditions, than as an indication of the constitution of the metals. This subject had lately received great attention in America. The Pennsylvania Railroad Company had charged their chemist, Dr. Dudley, to conduct chemical and mechanical tests of all rails on their line, some of which had done good service and others bad, and to compare them. His conclusions led to the following formula being recommended for and prescribed in their specifications for steel rails:—

Phosphorus not above	0·10 per cent.
Silicon „	0·04 „
Carbon between 0·25 and 0·35, say . .	0·30 „
Manganese	0·35 „

This metal was to have a tensile strength of 65,000 lbs. per square inch. Now this was all very well, but he thought it would be impracticable to carry it out in practice. He would strongly recommend engineers not to stipulate chemical compositions in their rail specifications, because the proper composition was not yet known, and even if it were, no rail-maker could undertake to produce it. This was the conclusion arrived at when Dr. Dudley's Paper on the chemical composition and physical properties of steel rails was discussed before the meeting of American mining

Mr. Sandberg.

engineers.[1] He had received confirmatory evidence of the correctness of this view from what had happened on the Cologne Minden railway on the 26th of December, 1879. A steel rail broke in no less than seventeen pieces by the express train passing over it, fortunately without accident. The rail had been laid six years, and the pieces analysed and tested gave just the results that Dr. Dudley prescribed, or very nearly so. The steel contained—

Carbon	0·024 per cent.
Phosphorus	0·080 „
Sulphur	0·030 „
Manganese	0·120 „
Contraction of area	54·500 „
Elongation	25·000 „
Tensile strength	5,000 kilogrammes per square centimètre.

With the prescribed physical and chemical conditions fulfilled, still breakage would occur, and he thought it would be well to wait a few years longer before stipulating conditions which might not be safe, and which, with the present mode of manufacture, makers would be unable to carry through.

Finally, he might mention that he had been commissioned by the Swedish Royal Administration of Government Railways, ten years ago, to visit Russia to investigate the effect of severe cold on iron and steel used as railway plant, and from the private report "On Railways in countries with a cold climate," which he had made, after careful study on the spot, he would quote the following conclusions:—

"There can be no doubt that iron and steel are very sensibly affected by changes of temperature, and the more extreme these changes are, and the more suddenly they are brought about, the greater will be the extent to which the strength of the material is affected. In support of this proposition I may state that in St. Petersburg, where the climate is more changeable than in Moscow, the evil effects are more keenly felt, and the railway plant is much more subject to breakage. In St. Petersburg the temperature in winter often changes from 0° to −40° C.; but in Moscow, when once the winter has set in, the cold is much more constant.

"Since great differences exist in the quality of iron, and in its power to resist any particular kind of strain, it behoves every railway engineer to select in any given case that kind of iron whose chemical composition shall best suit it to the special work in question, and also to study its mechanical properties, so that it may be adapted to the kind of work which it may have to perform.

[1] *Vide* Transactions of the American Institute of Mining Engineers, vol. vii., p. 201,

Mr. Sandberg. Thus, we find that the presence of phosphorus in iron has the most injurious effect when the metal is exposed to concussion at a low temperature, while its effects are by no means equally prejudicial to the tensile strength of the iron at the same temperature; hence such metal, when exposed to severe cold, will break like cast iron under a blow, but may nevertheless be able to sustain the same dead load in winter as in summer.

"Styffe's theory, which refers the greater brittleness of iron in winter solely to the increased rigidity of the supports on which the metal may rest, is contradicted by the experience gained on the Russian railways upon a much larger scale than in my own experience at Stockholm—experiments which were described in an Appendix to my translation of Styffe's work 'On the Strength of Iron and Steel.' Doubtless the elasticity of the base on which the metal rests does considerably affect its strength, but even if the supports have the same elasticity in winter as in summer, as would be the case with a granite rock, it is found that the more phosphorus the iron contains the more readily will it break on exposure to concussion at a low temperature. Such iron should therefore be confined in its use chiefly to countries which enjoy a temperate climate, or should be applied to such objects as are not subjected to the effects of concussion, such as roofs, buildings, plates, &c. In a railway, however, it should be borne in mind that the road when high speed is used must be subjected to concussion as well as the rolling stock—a fact which is proved by the greater number of accidents which have occurred upon increasing the speed. Indeed, experience in Russia shows that the higher the speed the more numerous are the breakages, these being consequent upon the sharper concussion due to increased speed. Both iron and steel may be regarded as composed of an assemblage of numerous small crystals, the cohesion between which—and, therefore, the strength of the metal—will be affected by the amount of phosphorus present; the effect of low temperature seems to be to lessen the cohesion between the component crystals, and hence the diminution of strength consequent upon reduction of temperature. Instead of entering upon any theoretical explanation of these phenomena, I prefer proceeding to the conclusions which may be legitimately deduced from the facts known to practical men, and which may be useful to the railway authorities in guarding against the disastrous effects of extreme cold. In stating these conclusions it will be well to arrange them in the corresponding order to that given above, and to treat successively of the road, the rails, and the rolling stock.

"The great point in connection with the road is to secure Mr. Sandberg. effective drainage, and to have it well laid with good coarse ballast. The sleepers must be large and numerous, for the more wood that enters into the construction of the line, the greater will be its elasticity. The rails should be placed directly upon the sleepers without the interposition of sole-plates, as these cause a shock to be communicated to the rolling stock at every joint. The joints should, if possible, be as stiff as the rails are in the middle, so that the road may become almost one continuous structure. My standard sections lately published have been designed with a view to securing these objects. The rails should be made either of steel or of iron, free from phosphorus. For their durability and safety, steel rails seem to have gained favour as much in Russia as in Canada. I have just received a letter from the Engineer-in-Chief of the Great Western railway of Canada, who writes as follows: 'We have now a gross traffic of 2¼ millions of tons per annum upon a single road, and cannot get iron rails to last over an average of four years, and hardly so long on heavy gradients. We are therefore now introducing steel rails of 65 lbs. per yard, and last autumn 1,000 tons were laid. Very soon after they were put down about twenty bars broke, but we have had no breakages subsequently. This has been almost the universal experience gained on all American railways. Several rails break almost immediately, no doubt owing to slight imperfections, but after these first defects exhibit themselves no further fractures take place. Steel rails, therefore, require equally as careful inspection as iron rails.' Steel-headed rails are giving good results in America and in Sweden, and therefore the bad results obtained in Russia must be referred to inferiority of manufacture. Iron rails should not contain phosphorus, and should be tested by the inspector at the works by means of blows powerful enough to ensure safety. The Russian test of 6 cwt. falling through 7 feet on a 72-lbs. rail has been found to be too mild, and rails which in England at the works have withstood such a shock have broken during a Russian winter. On the other hand, the Swedish test of 15 cwt. falling 7 feet on a 66-lbs. rail has been sufficient to secure the railways of Scandinavia ever since their commencement from a single breakage of rails. Having been charged with the inspection and testing of rails for the last twelve years, for Governments as well as for private railways, in Sweden, Norway, and Denmark, I have had more than one hard struggle with the rail-makers about the test of rails. The results in practice in Sweden as compared with Russia I am proud of stating. The question of determining a medium test having arisen among rail-makers, I have

Mr. Sandberg. been led to adopt the following rule for the ball-test: The weight of the ball expressed in cwts., multiplied into the height of the fall in feet, should be equal to the weight of the rail per yard. Tests based on this method stand between the extremely severe Swedish method and the mild Russian test, and yet, according to my opinion, secure safety even in a cold climate. It appears that Welsh rails are preferable to those of Cleveland, since the former do not contain phosphorus, while the latter contain ¼ per cent. in the rails, and not less than 1¼ per cent. in the pig iron; hence it is seen that 1 per cent. is expelled during puddling. The fact of certain rails made in Wales proving as brittle as those made in Cleveland is to be explained by Northampton ores having been mixed with the Welsh ores. Even in Wales strict care must be taken to avoid the production of brittle rails, and no better and more practical method for ensuring safety has yet been found than that of frequently examining samples by the test of concussion. As there are frequent changes in the management of rail-mills, and in the quality of the iron employed, and as it may happen that a maker who deserves a good reputation one year may neglect the quality of his rails the next year, it does not appear expedient to arrange the different works in classes according to the quality of rails produced, but it should rather be remembered that all makers can manufacture both good and bad rails; and if, therefore, railway engineers do not strictly look after their interest by careful inspection, they must naturally become sufferers.

"In regard to rolling stock, Mansel's wooden wheels, with retaining fastenings of the tire, seem to be the perfection of a wheel for cold climates. Cast-iron wheels may be economically employed where the speed is low, but they are neither safe nor economical for high speed, such as 20 miles per hour. Bessemer steel is the most economical for tires, and, if made of good raw material, is quite safe. The bad results attending the use of Bessemer steel in the form of rolling stock in England and Belgium, as stated above, will tend to check the introduction of Swedish Bessemer steel into Russia. And yet nowhere would Bessemer steel be better applied than for axles, tires, and rails in Russia, provided that due care were taken to secure uniformity and homogeneity in the manufacture, and to maintain the proportion of carbon between ¼ and ⅓ per cent. Better means of communication throughout Sweden, the concentration of the works, and improved management and negotiations, are the three conditions necessary for the Swedes, in order to attempt a successful trade with their eastern neighbour. Russia, with its bad climate,

is indeed equally as much in want of the splendid iron of Sweden for the development of her railways, as the Swedish iron trade, which is at present ruined, stands in need of the Russian market for its revival. Axles should be made of the best iron, or of the best cast steel. If Bessemer steel be used it must necessarily be of better quality than that which has hitherto been supplied to Russia by Belgium and England, and which has given the bad results already detailed. Every portion of the engines must necessarily be of the best material and workmanship. Cast steel seems to have gained general favour amongst Russian engineers, and is recommended both for safety and economy, while Bessemer steel is regarded with decided suspicion. There is, indeed, no doubt that Bessemer steel is not so homogeneous as cast steel, and it is difficult to make pot-steel as regular and uniform as iron. This is certainly the cause of the general objection amongst engineers to substitute steel for iron. There are, however, grounds for asserting that steel suffers less from the effect of cold than iron does, particularly if phosphorus be present in the iron. Any means tending to confer elasticity on the rolling stock is certainly desirable, such as the use of indiarubber as extra springs, and of a large quantity of wood rather than iron in the rolling stock and permanent way. The slackening of the speed in winter seems advisable, both on the score of safety and of economy." Mr. Sandberg.

Mr. COLLINGHURST SCHREIBER, of Ottawa, after carefully watching the behaviour of iron and steel for many years, was firmly impressed with the conviction that they crystallised and were fractured with great ease when subjected to a very low temperature; and more especially was this the case when a sudden change took place from cold many degrees below zero to above the freezing point. Upon these occasions the breakages of rails and car wheels increased immensely, but immediately the metal was warmed up, its tenacity of structure apparently returned. With these sudden changes in the temperature from cold to heat, he had had to record steel rails flying into as many as twenty pieces, in lengths ranging from 6 to 18 inches. His notes went to show that, in a series of years, the breakages during the warm period of the year, say from May to December, as compared with the other six months of the year, were: steel rails as 1 to 30; iron rails as 1 to 45; cast-iron car wheels as 1 to 3½. It might be argued that this was brought about by the solidity of the frozen surface, and to a certain extent no doubt this was the case, the rigidity of the permanent way in winter contributing towards this result. At the same time he was convinced that the large preponderance in the number of breakages Mr. Schreiber.

Mr. Schreiber. during the cold period over those of the summer season, was to be attributed to the change which the structure of the metal underwent at a low temperature. He had never made any scientific experiments as to the relative strength of these metals in cold and warm weather, but he had been a close observer of their behaviour under varied circumstances; and it would be difficult to convince him that extreme cold did not impair their strength. He would give an example. He frequently had occasion to curve both iron and steel rails to a small radius; during warm weather this could be accomplished with freedom from fracture, whereas in the cold season (unless the metal was baked before a fire first) it was impossible to put them through the operation without breaking them. He might add another example. In drilling rocks in summer, such an occurrence as a runner "flying" was unheard of; whereas when the thermometer ranged from 25° to 55° below zero, it was not an uncommon occurrence. He must acknowledge that these were no scientific tests; but while they afforded no data upon which to found a calculation as to the strain these metals would safely bear in a very low temperature, they nevertheless, he considered, established the fact that the strength of the metals was impaired by cold, and that what might be considered as a factor of safety in a moderate climate, could scarcely be relied upon in a severe one, like that of Canada.

Mr. Wilson. Mr. J. M. Wilson, of Philadelphia, from twenty years' experience of the line of the Pennsylvania railroad, during fifteen of which he had had direct charge of the bridges, from the preparation of the designs until their erection, and subsequent annual ordinary inspection, was of opinion that, while iron was more liable to break under shocks or jars in cold weather than in warm, the question did not practically affect the strength of the material when the working stress did not exceed the standard limits, which were essentially the same as in England. Where material was under an excessive strain, and breakage might occur in warm weather, the percentage of breakage was considerably greater in winter than in summer.

In the matter of rails, complete records had been kept by the Pennsylvania railroad company for twenty years, on blanks prepared for the purpose, and reported monthly, the cause, or probable cause of breakage being always inserted in the report. The causes given were various, such as "flat wheel," "defect in iron," "frost," &c., whatever the foreman or supervisor of the division might decide. Breakages were always much greater in winter than in summer, especially when the system of reporting was first insti-

tuted. Of late years, however, owing to the introduction of heavier rails, and of steel, breakages had been few. It was the opinion of American engineers that the increase of breakages in winter was due more to the rigidity of the frozen road-bed, acting as an anvil under the rail, than to any brittleness of the material from the cold. The thermometer was sometimes from 10° to 20° below zero. Mr. Wilson.

In reference to iron bridges, some of these had been in use on parts of the road ever since its completion, dating back to 1851, and were therefore twenty-nine years of age. The earlier bridges were computed for a live load of only 1 ton (2,000 lbs.) to the lineal foot of track, and being too light for the present traffic, had gradually been strengthened or replaced by heavier structures. Only three of these bridges were now left; one of them was to be replaced this year. They were of the "Pratt" truss form,[1] with cast-iron upper chord (boom); four wrought-iron bars for the lower chord; cast-iron vertical posts, wrought-iron brace rods, cast-iron upper and lower angle blocks, cast-iron arch, and cast lugs on the posts bearing on the arches. Rarely was any of the cast iron broken; sometimes the central angle blocks, from their shape and connection with the brace rods, had tension thrown on them. Where these were broken they had been replaced by malleable castings. The upper chord sometimes was broken, owing to rigidity over the pier, and the continuity of the chord was destroyed. Considerable load had always been adjusted on the arch in this type of bridge, without any trouble with the cast iron, either in the arch or in the bearing lugs on the posts; none of the latter had ever been known to shear off. Wrought-iron brace rods had, however, been broken from time to time, especially in winter, and it had always been customary to keep some rods on hand on the subdivisions of the road, to replace any that might be broken. In case of a rod breaking, the arch would always carry the structure until it was replaced. These brace rods were not "upset" at the screw, and have always been broken at the screw thread, that being the weakest point. All the rods were considerably overstrained. In other bridges there were no cases of winter breakage with rods up to the standard strength. He would venture the opinion that this question of cold was somewhat similar to the introduction of carbon in steel. The cold increased the strength under a steady tension, but at the same time rendered the material more brittle. Cast iron, being naturally far more brittle than wrought iron, the percentage of increase for the same number of degrees of cold was

[1] *Vide* "The Pennsylvania Railroad." By James Dredge, p. 53.

Mr. Wilson. much greater, not depending upon and varying as the strength of the material.

In conclusion, he submitted a Table of the number of steel rails broken in the main tracks of the Pennsylvania railroad during the years 1875 to 1879, inclusive:—

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Totals.
1875	50	118	55	9	2	0	2	4	5	3	5	4	257
1876	6	13	7	8	0	2	4	5	10	19	5	27	106
1877	69	20	17	5	6	0	0	1	7	2	8	3	138
1878	7	4	3	2	0	4	1	0	5	1	4	9	40
1879	30	21	19	3	5	2	4	3	1	4	10	16	118
Totals .	162	176	101	27	13	8	11	13	28	29	32	59	659
Average	33	35	20	5	3	2	2	3	6	6	7	10	132

It would be noticed that, while in general there was a large increase in breakage during the winter months, yet there were some discrepancies. Thus, in 1875, as many rails were broken in August as in December. In 1876, the number broken in October (a mild month, with seldom any frost in the ground) was far greater than in January or February.

Mr.Wrightson. Mr. T. Wrightson remarked that apart from chemical considerations, the strength of iron to resist strains depended much upon the physical conditions under which the iron was allowed to cool from its higher temperature in course of manufacture. The rate and equability of cooling and the form and dimensions of the iron itself were all conditions of importance. If a bar of wrought iron was heated to white heat and allowed to cool without hammering it deteriorated in strength. The molecules of the iron were at a greater distance apart when in a plastic state. In cooling, the outside portions of the bar would contract first, but could not return to their natural position, as the inside of the bar would still be at its higher temperature. The hammering or rolling caused an adjustment of the molecular distance, and the iron thus became homogeneous throughout. The method of cooling also altered the molecular distance. He found from experiments that best bar iron, when heated to redness and cooled suddenly in water, contracted permanently in its linear dimensions 0·125 per cent. for each immersion. A bar of common iron contracted about 0·15 per cent. He had by repeating the process shortened a bar 30 inches long about 2¼ inches in fifteen heatings and coolings.

This shortening was not to be explained by the oxidation of the ends, which was very trifling. Other experiments had also shown that cast iron, copper, and steel were variously affected in their molecular state under different conditions of cooling. Mr. Wrightson.

That the action of heat and mechanical vibration had the effect of rearranging the molecules in some way, so as to vary the character of the metal, was well known. Chains and wheel-tires, &c., became brittle by continued use. The re-adjustment of the molecules was effected by the curious process of annealing, which was simply heating to a moderately high temperature, and then allowing to cool slowly. This seemed to restore the tenacity of the iron, and instead of breaking with a crystalline section, the iron became what was called fibrous once more. A few years ago he had carefully examined the iron cut from the plates of two different boilers, both of which had ripped at the seams and caused explosion. The heat acting on the boiler had through time so affected the iron at the thick seams as to make it brittle, and apparently crystalline in fracture, although not much affected in tensile strength. Farther from the seam the iron was, in the case of both boilers, less injuriously affected. He then took strips of the iron at the seam rip and heated them to a dull red, cooling them afterwards gradually in sawdust; after this process the brittleness disappeared and the fibrous character of the iron was restored. Thus molecular motion, whether from mechanical energy or from heat, appeared after long application to alter the disposition of the molecules and to injure the quality of the iron. The remedy of the evil lay in annealing the iron in both cases.

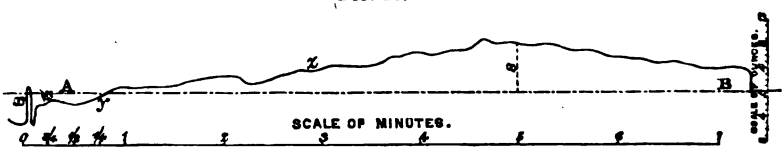
The treacherous manner in which steel and iron occasionally gave way was in a great measure to be attributed to internal strains existing in the material before the ordinary strain due to its work came upon it. These internal strains were the result of unsuitable forms of material and unequal cooling of the parts when solidifying. What engineers wanted was a more accurate knowledge of the physical changes occurring in metals at the time of solidification and cooling from high temperatures. Information on this subject was very difficult to obtain, and the opinions of metallurgists varied with regard to the simplest observations. Thus many had held that iron expanded in solidifying, others that it contracted. Mr. Robert Mallet, M. Inst. C.E., in a Paper read before the Royal Society in 1874,[1] claimed to show that, with the exception of water and perhaps bismuth, no sub-

[1] *Vide* "Proceedings of the Royal Society of London," vol. xxii., p. 366.

Mr. Wrightson. stance had been proved to expand in passing from the liquid to the solid state, and cited observations and experiments from which he inferred that no such expansion could occur in the case of iron.

This diversity of opinion as to simple facts appeared to demand more exact measurement than he could find had been applied to any of the observations recorded. He therefore last year designed, and had constructed, an instrument for measuring exactly the change of volume of a body of metal as it passed from the solid to the liquid state. The principle of the instrument was as follows:—He attached a ball of the metal to be examined to a rod which was suspended from a sensitive spiral spring. This ball was submerged in a ladle of the same metal in a molten state. As the ball rose in temperature it expanded and displaced more and more of the liquid metal. This displacement of the metal varied the flotation, and this variation was read off in ounces on the spring balance. Thus, if the ball expanded to such an extent as to displace 4 more oz. of liquid metal than it did when first submerged, the flotation would be increased 4 oz., and this amount of relief to the spring could be read off to a scale of weights. By connecting a pencil point to the moving part of the spring balance, and allowing it to press on a piece of paper wound round a cylinder which revolved by clock-work, he had been able to get an automatic register of the gradual expansion of the metal ball, the vertical ordinates of the diagram showing the weight of metal displaced by expansion, and the horizontal line giving time. These diagrams were very instructive, and showed that ordinary foundry iron was at its maximum density when in a solid condition, at its minimum density when in a plastic condition immediately before liquefaction, and that in liquefying it came back to a density intermediate between these two, being very little less than that of its cold state.

FIG. 13.



Weight of ball and portions of stalk immersed . . .	252¼ oz.
Specific gravity of ditto	6·96
Maximum sinking effect	1½ oz.=0·6 per cent. of 252¼ oz.
„ floating „	8 oz.=3·17 per cent. of ditto.

Specific gravity of fluid metal = 0·6 per cent. less than 6·96 = 6·92.

Fig. 13 was a diagram of the melting of a 5-inch ball taken from his instrument. The horizontal line A B gave the position

of equilibrium, when, if the ball was of the same specific gravity as the molten iron, there would be neither a sinking nor a floating effect. When the ball was first submerged the pencil went to position x below the equilibrium line, showing that the ball had a sinking effect of $1\frac{1}{2}$ oz. As the heat of the molten iron penetrated the ball, it expanded, displacing the metal. By a mechanical arrangement which lowered or raised the whole apparatus, the ball was always kept exactly the same distance below the metal, and thus the variation in the spring was a faithful record of the variation in volume. It would be noticed that there was a sudden fall on the right of the diagram. This was when the ball melted. After the ball arrived at its greatest volume it was in a soft plastic condition, as he had shown by pulling several balls out at this stage, when he had found that an iron pin could be thrust through and through the mass as though it were putty. As soon as the ball began to melt, the vertical ordinates were useless to determine the specific gravity of the ball, as the mass was altering; but it appeared from the diagram as though the iron, when in this highly plastic state, rapidly passed into the liquid condition, the descending line returning to the position of equilibrium, in consequence of the ball having disappeared in the general molten mass. The small fluctuations in the line of the diagram were only due to slight disturbances of the spring in keeping the stalk of the ball free from floating scoria. Mr. Wrightson.

Now if the diagram correctly represented the changes in passing from solid to liquid when read from left to right, a reversal of the reading ought to give the changes in passing from the liquid to the solid state. From this it would be seen that there was a considerable and sudden expansion as the metal became plastic, and that it then contracted more gradually until its density was a little greater than the density of the molten iron. It was an old puzzle amongst engineers to explain why solid cast iron floated in liquid cast iron. The explanation was to be found in the lines on the left hand of the diagram. When the iron was thrown into the ladle the expansion was so rapid that in a second or two it floated. If, instead of throwing it, the ball was lowered into the ladle on an iron fork, as he had frequently done, it would be found that it sank, and then rose in a few seconds to the surface. Of course it was possible to cast and cool a ball in such a way as to have a specific gravity which would compel it to float at once, but he was speaking of castings of average and usual density made of ordinary foundry iron. He had the pleasure of showing these diagrams at the Liverpool meeting of the Iron and

Mr. Wrightson. Steel Institute in 1879,[1] and since that time had tested the truth of the theory of the change of volume by casting a large 15-inch ball of Cleveland foundry iron, and measuring its diameter at intervals until cold. The expansion was most evident, and the ball continued to increase in size for half an hour after the metal was run into the mould, subsequently contracting to a dimension a little less than the mould was originally made, exactly as shown by the reversed reading of the diagram.

It was not an unusual occurrence in the case of a cast-iron plate that days after it had been cooled it would, without apparent reason, fly in pieces, sometimes with a loud report like that of a pistol. A consideration of the cooling of such a plate, referred to in the diagram of changing volume, at once revealed the cause of this. If one portion of the plate had been cooled rather in advance of the adjoining portion, its condition of volume would be expressed by a position lower down the descending line on the left of the diagram, than that expressing the volume of the portion of plate left at a higher temperature. When this unequal condition of the metal existed, internal strains were produced, which might be so great as to permanently injure the quality of the iron at the part strained, and this tension, if near the limit of the strength of the iron, only required a slight additional strain to cause rupture. The same cause might probably be at work in producing the frequent fractures in steel. This material was looked upon by many engineers as treacherous, but he would submit that an exhaustive set of experiments, carried out on the change of volume in steel when passing from a high to a low temperature, would probably lead to alterations in the treatment of steel in manufacture, which would overcome the existing objections raised against the material.

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17 February, 1880.

WILLIAM HENRY BARLOW, F.R.S., President, in the Chair.

The discussion upon the Paper "Iron and Steel at Low Temperatures," by Mr. Webster, occupied the whole evening.

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[1] *Vide* "The Journal of the Iron and Steel Institute," 1879, Plates 6 to 10.

Styrian Cast Steel for Tools.

Messrs. Böhler Brothers and Company, of Vienna, exhibited, at a subsequent meeting, two cases containing fractured specimens of tilted ingots of cast steel for tools, remarkable for extreme regularity of structure, the fractures being of a fine silky character in the harder qualities, and uniformly granular in those of a softer kind. They were made at Kapfenberg and Bruckbach in Styria, by the fusion, in crucibles, principally, of blister and refined forge steels, produced from the spathic ore of the Erzberg of Eisenerz. This is the largest known deposit of that substance, and is also celebrated for the extreme purity of the product, which, though containing less manganese than the spathic ore of Siegen, is almost absolutely free from copper and sulphur. Charcoal and vegetable fuel only come in contact with the tool-steel and all the materials it is made of in the smelting processes where the metal is brought into contact with the fuel. The tilting of the bars is entirely done under helve-hammers, driven by water power, except in some of the larger sizes, where steam is used; but rolling mills are entirely dispensed with. The special qualities of the different numbers are given in the Table of tests (see next page). That marked 0, the hardest, contains tungsten, and has the characteristic almost glassy fracture, due to the presence of that element. Those of a softer character, distinguished as extra hard, medium hard, tough and soft, all contain manganese and silicon in suitable proportion, the latter being derived from the material of the crucible by the action of manganiferous substances added in the fusion.

The following are complete analyses of three qualities:—

	Extra Hard. 3.	Between First Quality Hard, and First Quality Medium Hard.	First Quality Tough. 5.
Carbon	1·189	0·943	0·638
Silicon	0·289	0·382	0·388
Phosphorus	0·023	0·027	0·029
Sulphur	0·008	0·011	0·013
Copper	traces	traces	traces
Cobalt and nickel	„	„	„
Manganese	0·371	0·328	0·446
Trace by difference	98·150	98·309	98·491
	100·00	100·00	100·00

The first and last of these correspond to the samples where mechanical tests are given in the succeeding Table, but the second is not so represented.

EXPERIMENTS on STRAINS of DIFFERENT QUALITIES of CAST STEEL from the KAPFENBERG WORKS.

By the Imperial and Royal Academy of Mines, Leoben.

Quality.	Hardness Number.	Tensile Strain. Limit of Elasticity.	Tensile Strain. Limit of Rupture.	Total Percentage of Stretching.	Proportion of Section of Rupture to Original Section.	Proportion of Carbon.	Uses and Observations.
		In Kilogrammes per Square Millimètre.					
Special—very hard .	0	48·64	81·71	6·37	0·9175	1·123 — 2·300	Extremely hard; for working hardened steel, chilled, cast, &c.
Extra hard .	1	33·69	76·63	5·09	0·7535	1·350	Very hard; especially appropriate for revolving cutters, planing machines, tools for dressing millstones, &c.
	2	35·98	75·64	5·59	0·8245	1·189	
	3	31·41	72·99	11·45	0·7995	1·010	
Extra medium hard .	4	32·87	73·04	12·52	0·6500	0·850	Hard and tenacious; for screwing tools, drilling bits and bores, planes and cold punching machines, blades of jointers, paper cutters, punches, &c.
First quality, hard .	1	36·45	78·51	8·26	0·7740	1·150	Very hard; for turning and planing tools.
	2	33·79	70·41	11·65	0·6230	1·000	Less hard.
..	3	30·04	69·98	4·50	0·6705	0·850	Hard; for the bits of boring machines, for the blades of mortising machines, pointers, and tools for working hard stone, for blades of shears, &c. All the above forge well at a red heat.
First quality, medium hard .	4	26·27	65·67	6·48	0·6495	0·750	For the bits of iron-boring machines, punches, shears and cold-cutters, polishing hammers.
First quality, tough .	5	33·35	74·14	9·00	0·5235	0·638	Specially fit for valves, axles, punches, and drills of soft stone, for large cutters of sheet iron, hot-punchers and cutters, for steeling delicate instruments. Forges and welds well at red heat.
First quality, soft .	6	37·05	72·27	7·37	0·744	0·581	For smiths' riveters, and for steeling large surfaces. Forges and welds well at a red heat.
Cast steel	7	24·84	48·78	19·57	0·5925	0·414	For gun barrels, and the breech actions of fire-arms. Forges and welds well at a white heat.
..	8	18·51	52·76	20·38	0·6145	0·585	For scythes. Forges and welds well at a white heat.

24 February 1880.

JAMES BRUNLEES, F.R.S.E., Vice-President, in the Chair.

(*Paper No. 1673.*)

"On the Use of Asphalt and Mineral Bitumen in Engineering."

By William Henry Delano, Assoc. Inst. C.E.

In the year 1876 the Author translated for the Institution a memoir by M. Ernest Chabrier, civil engineer, "On the Applications of Asphalt."[1] This Paper, and the well-known work of M. Léon Malo on the same subject, are exhaustive as regards the general question.

The object of the present communication is to give a description of certain executed works, with their cost, an account of various failures that have been overcome, and such information concerning the quality and preparation of the material as will enable a supervising agent to ensure good work and discover fraud. The Author's personal experience is confined to France, particularly Paris, where he has been engaged since 1871 in the practical application of natural asphaltic compounds, and where the use of the material has obtained a position as one of the great industries of the country.

It is important that M. Malo's nomenclature should be adhered to in specifications. 1st. Asphalt is a natural product, a bituminous limestone, consisting of carbonate of lime and mineral bitumen, intimately combined by natural agency. 2nd. Asphalt mastic is the rock ground to powder and mixed with a certain proportion of bitumen similar to that originally contained in the rock. 3rd. Gritted asphalt mastic is asphalt mastic to which washed or river sand, free from all earthy matters, has been added. 4th. Asphaltic or bituminous concrete is gritted asphalt mastic

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 276.

in a hot state, mixed with dry flint or other stone. 5th. Bitumen is a mineral product found in asphalt rock in Trinidad and in other places. According to Boussingault, bitumen is composed of

Carbon	85	parts.
Hydrogen	12	„
Oxygen	3	„
	100	„

It is therefore an oxygenated hydro-carburet. It is not gas tar, nor Stockholm tar, neither is it pitch from suets and fatty matters, or from shale or petroleum.

The asphalts that have come under the Author's observation are those of Val de Travers, Seyssel, Sicily, Chieti in the Abruzzi, Auvergne, Lobsann, and Limmer. Analyses of various asphalts by M. Hervé Mangon and M. Durand-Claye, of the Laboratory of the École des Ponts et Chaussées, Paris, are given in Appendix A.

The engineer who is specifying asphalt for roadways, footpaths, water-proof coatings for arches, vaults, casemates, &c., may test the material thus:—A specimen of the rock, freed from all extraneous matter, having been pulverised as finely as possible should be dissolved in sulphuret of carbon, turpentine, ether, or benzine, placed in a glass vessel and stirred with a glass rod. A dark solution will result, from which will be precipitated the pulverised limestone. The solution of bitumen should then be poured off. The dissolvent speedily evaporates, leaving the constituent parts of the asphalt, each of which should be weighed, so as to determine the exact proportion. The bitumen should be heated in a lead bath and tested with a porcelain or Baumé thermometer to 428° Fahrenheit. There will be little loss by evaporation if the bitumen is good, but if bituminous oil is present the loss will be considerable. Gritted mastic should be heated to 450° Fahrenheit. The limestone should next be examined. If the powder is white, and soft to the touch, it is a good component part of asphalt, but if rough and dirty, on being tested with re-agents, it will be found to contain iron pyrites, silicates, clay, &c. Some asphalts also are of a spongy or hygrometrical nature. Thus, as an analysis which merely gives so much bitumen and so much limestone may mislead, it is necessary to know the quality of the limestone and of the bitumen.

For a good compressed roadway, an asphalt composed of pure

limestone and 9 to 10 per cent. of bitumen, non-evaporative at 428° Fahrenheit, is the most suitable. Asphalts containing much more than 10 per cent. of bitumen get soft in summer and wavy; those containing much less have not sufficient bind for heavy traffic, although asphalt containing 7 per cent. of bitumen, properly heated, does well for courtyards, as it sets hard when cold.

Asphaltic rocks, rich in bituminous matter, generally contain volatile oils. In the Author's opinion it is not safe to specify any asphalts for roadways that have not withstood at least three cold winters and three hot summers.

Trinidad bitumen is now largely used to mix with asphalt powder for mastic. In the raw state it contains from 40 to 45 per cent. of dirt, and 35 per cent. of water. It is refined by mixing with it about one-third its weight of schist or shale-grease (*i.e.*, the pitch remaining after the lighting and lubricating oils have been exhaled in distillation), and heating the mixture for twenty hours, after which it is passed through a fine colander and decanted. The theory is that the shale grease and water are evaporated, the earthy matters precipitated, and the other extraneous matters screened out. There is always a residue, however, of about 20 per cent. of fine clay in purified Trinidad bitumen, and sometimes much more. In testing, the easiest way is to dissolve the bitumen in sulphuret of carbon, and to strain the solution through thick blotting-paper, which retains and gives the proportion of the clay, which should not exceed 20 per cent.; afterwards using the evaporative test already described.

Roadways of Compressed Asphalt.

It may be taken for granted that the use of asphalt roadways is now approved in England. The various reports of Mr. William Haywood, M. Inst. C.E., are conclusive on this point. No roadway is perfect; but the Author is of opinion that, for cities with heavy traffic, and where the gradients do not exceed 1 in 50, a well-laid surface of compressed asphalt is near perfection. It is noiseless, does not vibrate, produces neither dust nor mud, is cheap and durable, easily repaired, and the old material can be used again. The best foundation is a bed of Portland cement concrete 6 to 9 inches thick, with as little floating as possible, laid on a resisting subsoil. The surface of compressed asphalt powder should be

from 2 to $2\frac{5}{8}$ inches thick. The present price of a compressed asphalt roadway per square mètre is, in Paris, for ordinary traffic:—

	Francs.	Cents.
Portland cement concrete, 6 inches thick	5	25
Compressed asphalt, Seyssel or Val de Travers, 2 inches thick	14	15
	19	40

or, say, about 13*s*. per square yard. But the distance from the mines influences the cost of the material.

The first asphalt roadway laid by the Author was in the Rue d'Antin, Paris, in 1872. With the exception of a piece cut off for the New Opera avenue, it has stood perfectly well to the present time. It replaced a causeway of granite sets, and one-half the expense was paid by the landlords of the street. As the engineers of the city were only able to specify a layer of 4 inches of hydraulic lime concrete, the extra cost of laying the 2 additional inches of concrete and the Portland cement was paid by the Compagnie Générale des Asphaltes de France, who had contracted to maintain for six years the roadways and footpaths in compressed asphalt and mastic. On each side of the roadway were placed gutters of Belgian granite sets, 16 by 20 centimètres and 60 centimètres wide, with cement-mortar joints, and a fall towards the kerb of 1 in 28. This was done by order of M. Alphand, Director of Works of Paris, who had noticed that the greasy water, which runs from the houses into the gutters, in streets where there are no drains, rotted the asphalt, and that the consequent repairs were difficult owing to the habit of flushing the gutters with pure water several times a day. This difficulty does not exist in streets where there are drains.

In laying the concrete, the screeds were set so that there should be a fall on each side of the crown of the roadway of 1 in 50. The average width of the roadway was 17·7 feet, and the longitudinal fall about 1 in 100. The asphalt powder was ground fine in a Carr's disintegrator, heated in a yard $1\frac{1}{2}$ mile distant to 284° Fahr., carefully spread over the dry concrete, and rammed with hot rammers till the surface became resonant.

Appendix B gives a tabulated statement of the works executed by the Author, with the nature of the foundations, and observations as to duration.

Among the difficulties the contractor has to contend with in laying an asphalt causeway are the prejudices of the foremen, who

prefer tradition to reason. The tradition is that sand is incompressible; that sand makes a good foundation for granite sets, and therefore does equally well for concrete. Sand is incompressible in a cylinder, but under street traffic gets displaced, and absorbs water, causing the concrete to crack. The layer of compressed asphalt follows, and then unsatisfactory repairs are made, for repairs on a shifting concrete, through which the wet can rise, never last long. The Author, when executing such repairs in winter, had the surface sprinkled with dry cement, afterwards rammed, and then a layer of liquid asphalt run over it and allowed to cool, so as to have a dry surface on which to lay the hot powder.

When superseding granite sets by asphalt, the sand should be removed, and the concrete laid on the hard soil; for, just as hard granite sets require an elastic foundation, so does the slightly elastic surface of compressed asphalt require a rigid foundation. In preparing the foundation of the asphalt roadways of the Place de l'Europe and the Auteuil bridges, Paris, a coating of liquid asphalt $\frac{3}{8}$ inch thick was first laid down to keep out the surface water from the masonry, then a 3-inch bed of sand by order of the Government engineer, who feared lest the immediate contact of the rough concrete with the asphalt mastic would damage this coating. On the top of the sand was put a layer of 4 inches of hydraulic lime concrete, and on the top of the concrete 2 inches of compressed Val de Travers asphalt. The contracting company had agreed to keep these roadways in order during six years for 1 franc per square mètre per annum. The cost to the contractors was about 10 francs per square mètre per annum. The rain water filtered through the kerbstone into the layer of sand; in hard winters it froze, and forced up the concrete, and in summer the sand yielded under heavy traffic, causing depressions in the surface. The Author, finding the contract most onerous, proposed to the engineers of the city of Paris to lay the whole work afresh upon their paying only for one-half of the new concrete, and using up the sand for mortar. This offer was refused. Since the termination of the six years' contract the two bridges have been in worse order than ever; that at Auteuil is now nearly all macadam on one side; the Pont de l'Europe is honeycombed also in holes and lumps.

Experience has proved that hydraulic lime concretes are of little use for asphalted roadways; they do not set quickly enough for crowded cities, and are never dry, as is shown by the fact that,

whenever an opening is made to a gas or a water-pipe, the old lime concrete is found to be wet. In 1877 the Author laid the Pont Masséna, Paris, a railway viaduct, for M. Barabant, municipal engineer; but on the liquid asphalt coating, Portland cement concrete 9 inches thick was laid, and on the concrete a layer of 2¼ inches of Val de Travers compressed asphalt. This work has never moved, and may last from fifteen to twenty years, in spite of heavy goods traffic. In 1872 the Author inherited a ten years' contract for the maintenance of the asphalt roadway of Elbeuf bridge, covering 1,400 superficial mètres. This structure is of wrought iron, subjected to considerable vibration under traffic. The flooring is of Mallet's buckle-plates, covered with hydraulic lime concrete, with a layer of 2 inches of compressed asphalt superposed. Owing to the shape of the buckle-plates the concrete was of unequal thickness. The maintenance of the roadway under these conditions cost 10,000 francs per annum, whilst the sum paid by the Department of the Seine Inférieure was 1,400 francs, or 1 franc per square mètre per annum. The lime concrete broke up under the vibration, and the asphalt of course followed. As the repairs were continuous, application was made to the authorities to be relieved of the contract upon payment of an indemnity. The authorities declined. They had tried wood, which wore out; granite sets were too heavy; macadam was too expensive. To meet the difficulty of the vibration, it was resolved to replace the hydraulic lime concrete with bituminous or asphaltic concrete. The roadway was accordingly taken up, the old compressed asphalt was heated till it fell to powder; it was then mixed with refined bitumen to make it into mastic, to which 40 per cent. of dry grit was added, and with every 2 parts of this asphaltic mortar, 3 of hot flint stone were mixed. This concrete was laid down hot upon the buckle-plates, and well rammed and dressed till a hard and slightly elastic surface was obtained. Upon this surface a layer 2 inches thick of compressed Val de Travers asphalt was put down. This work was finished in October 1875. Up to August 1879 not a single repair had been made, though the traffic had much increased. In the Rue de Sèvres, in 1876, the Author replaced a roadway of granite sets by compressed asphalt, in front of the Hospital Necker and the Institution of the Infant Blind, and resolved to replace the hydraulic lime concrete specified by natural or Roman cements. The result was not satisfactory; the concrete crumbled under the heavy traffic, and a portion of the work had to be relaid.

From the foregoing it appears that, for asphalt, good foundations of Portland cement concrete must be laid not less than 6 inches thick, but a layer of 9 inches is better. Lime and Roman cement concretes should never be specified for heavy traffic. Bituminous concrete costs say £4 per cubic yard, and is too expensive for ordinary work, though invaluable in special cases. There is some difficulty in getting thoroughly burnt and finely ground Portland cement. Fraudulent mixing is practised, and marked casks are refilled with an inferior article.

The asphalt powder cannot be too fine. If it could be got like the stive dust in flour mills, or, as the French workmen say, "folle farine," it would be perfection. In heating it care must be taken to evaporate all the volatile bituminous oils. To this end the powder heaters should be open at each extremity and the powder well stirred. Great care must be taken that no wood, or foreign object, gets mixed with the powder, as it will cause a hole sooner or later. Sometimes, after three or four years, a chip of hard wood will work its way up through a layer of 2½ inches of asphalt under traffic. The Author in 1876 laid down a road in the Rue de Vaugirard with great care; a month afterwards there was a hole in the middle. Upon examination it was found that one of the workmen had left in the concrete his wooden screed, which had rotted. Mr. Edwin Chadwick, C.B., who has studied asphalt under the hygienic aspect, has designed an asphalt tramway for ordinary carriages, which should answer well, as asphalt properly laid is more durable than granite flags or iron rails.

Asphalt is not slippery *per se*, but it becomes so if a coating of greasy mud is allowed to remain upon it. Roadways of asphalt, from the same mines as used in London, are laid in Paris, and the complaint of slipperiness does not arise. This immunity is not the result of a drier atmosphere, as some have supposed, but simply that in the latter city the roadways are regularly swept and washed, whereas in London they are not.

The dampness of the atmosphere has an important bearing upon the question of the best material for carriageways in towns, and the Author has been at some pains to obtain trustworthy information on this subject. He hopes to establish the fact, that the alleged greater dampness of the air in London against that of Paris is to some extent imaginary, and that it is to want of scavenging alone that the slipperiness of asphalt roadways in London is attributable. By the kindness of M. Mascart, director of the Bureau Central Météorologique, he is able to give authentic figures showing the humidity in Paris for six years ending 1878. The

values of London are taken from the quarterly returns of the meteorology of England, published by authority of the Registrar-General.

TABLE of SEASONAL HUMIDITY. Saturation = 100.

Paris (Saint Maur).	1873.	1874.	1875.	1876.	1877.	1878.
Winter	86·6	88·5	87·6	89·5	86·2	88·3
Spring	75·0	71·8	66·4	69·9	76·8	77·0
Summer	78·7	67·8	77·3	69·6	75·1	78·7
Autumn	87·3	85·1	85·0	87·9	83·7	85·6
Means . . .	81·9	78·3	79·1	79·2	80·4	82·4
London (Greenwich).	**1873.**	**1874.**	**1875.**[1]	**1876.**	**1877.**	**1878.**
Jan.—March . . .	86·0	84·0	80·0	85·0	83·0	84·0
April—June . . .	78·0	76·0	88·0	75·0	73·0	79·0
July—Sept. . . .	77·0	77·0	81·0	74·0	76·0	79·0
Oct.—Dec. . . .	88·0	88·0	85·0	83·0	84·0	85·0
Means . . .	82·2	81·25	84·6	79·2	79·0	81·75

[1] Heavy rain-storms in spring and summer.

The means for the six years are, therefore, for Paris, 80·2; London, 81·5—a difference of dampness insufficient to exercise any appreciable influence.

In a Paper published in the "Annales des Ponts et Chaussées"[1] M. Vaissière, Chief Engineer, gives the total cost of the scavenging service in Paris as £195,000 per annum. This includes scraping, sweeping, and washing the streets, watering in summer, and clearing away ordinary snowfalls in winter. The Author has not access to the figures of the London Vestries, but he doubts if in the aggregate they spend much less in order to obtain a result which in comparison is wholly inadequate. In any case, in view of the advantages to the senses and health of the inhabitants, and the immense saving in the money value of goods now spoilt by mud and dust, he ventures to assert that an efficient system of scavenging similar to that of Paris would be cheaply obtained if its adoption cost five times the amount quoted above.

In asphalted streets, where no provision exists for washing the roadways by flushing from the hydrants, an arrangement has

[1] *Vide* Minutes of Proceedings, Inst. C.E., vol. l., p. 223.

been devised which is found to be economical and easy of application. The apparatus consists of a wrought-iron or wooden cart-body, mounted on four wheels, of which the two front ones swivel

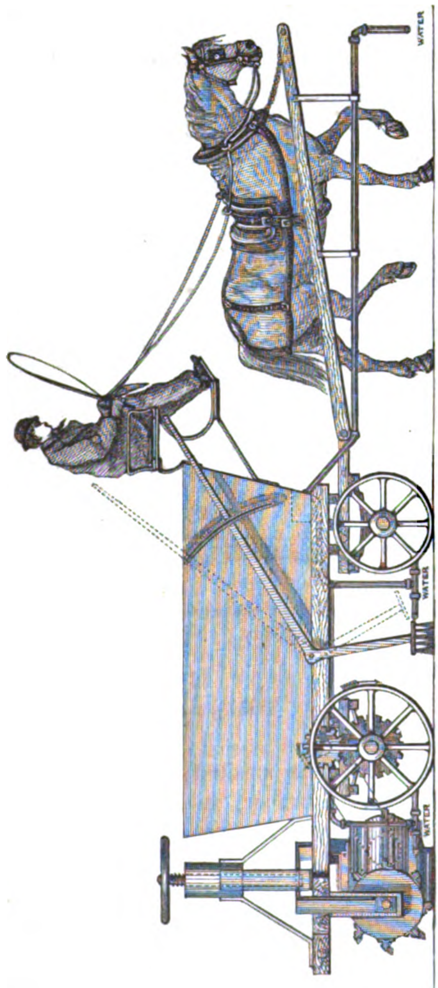


Fig. 1.

Water Cart.

freely, and drawn by two stout horses (Fig. 1). Under the shaft runs a jointed pipe, with a perforated delivery tube, set at right angles, and which can be raised or lowered by means of a rack. This delivers a shower of water in front of the horses, which

help by their tread to liquify the mud. The plan is adopted in Piacenza and other towns of Northern Italy, and is attended with no inconvenience to the horses, or otherwise. Behind the horses is a second distributor, which further dilutes the sticky mud, followed by an adjustable broom. Behind the broom is a third delivery pipe, followed by an adjustable revolving cylinder, set obliquely, and carrying a combination of bass brooms and "squeegees." The oblique set causes the diluted mud to be at once swept into the gutter. The capacity of the cart is 600 gallons, the three pipes distribute together 2 gallons per second, but this quantity can be regulated according to the state of the mud. Supposing the horses to walk at the rate of 6 feet per second, the tank will be emptied in five minutes.

The cost of this apparatus complete is taken at £70.

	£.	s.	d.
The interest and maintenance at 15 per cent. per annum would be per day	0	0	7
Wages of two men at 4s.	0	8	0
Two horses and harness	1	0	0
Total per day	1	9	7

Or say for two machines, £3 per day.

Adopting the figures given in Sir Joseph Whitworth's Paper on Street cleansing [1]—

	£.	s.	d.
One machine would do the work of seventeen men (sweepers) at 4s. per day	3	8	0
Cart, horse and driver	0	16	0
Total per day	4	4	0

Or for two sets £8 8s., as against £3 for the two washing and sweeping machines. Further, taking Sir Joseph Whitworth's estimate of 14,000 square yards per day, then the cost of cleansing a length of street of 60 yards, and, say 20 yards wide, would be 2s. 7d.; but it is fair to assume that a greater surface of smooth asphalt could be cleansed in the same time than of ordinary macadam.

The scavenging of Paris costs 2½d. per square mètre per annum, or say 2d. per square yard. A comparison between the two asphalted streets of Rue de Richelieu in Paris, and Cheapside, London, in muddy weather, shows the advantage of the Paris

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. vi., p. 431.

system of scavenging. Horses in Paris slip on the hard granite sets; they do not slip on asphalt more than on macadam, and on a level road start easily when loaded.

Compressed asphalt is not affected by heat, except that it becomes slightly soft, but without losing its ring under the horses' hoofs, and extreme frost has no effect upon it; but in case of any cracks or holes they will get gradually enlarged under the action of repeated wet thaws. It is easy to clear snow off asphalt, much more so than off any other paving.

The Author has used asphalt bricks and cubes for paving; but even under the most favourable circumstances the employment of powder is preferable. It is not easy to effect repairs in asphalt sets from the fact that, when under traffic, compression is going on, and the new sets, not having the same density as the old, rise above them and so get chipped.

Compressed asphalt gives no spark when struck, which makes it valuable for the floors of powder magazines, cartridge manufactories, &c. The French Artillery have used it for this purpose at the School of Pyrotechny at Bourges, and at the Donjon of Vincennes, and the Military Engineers have employed it at the fort of Génicourt, near Verdun.

Compressed asphalt is used in gateways like those of the Place du Carrousel, and the Place des Vosges, Paris, to absorb vibration and thus to prevent the destruction of architectural ornaments, &c.

The extent of surface of compressed asphalt in the public streets of Paris is 309,000 square mètres—or 370,000 square yards—not taking into account the numerous courtyards, gateways, and passages for private use.

Qualities of various Asphalts.

With regard to the quality of the various asphaltic rocks, the Author submits the following opinion:—Val de Travers rock is sure to give a satisfactory result if properly ground, heated, and laid on a good foundation. It is, however, sometimes too rich in bitumen, in which case it must be heated longer and well stirred, to get rid of the volatile bituminous oils. An admixture of 25 per cent. of old Val de Travers compressed asphalt, cleaned, ground up and passed through the pulverising machine simultaneously with the new rock, so as to get thoroughly mixed, is of advantage with rich asphalt; but it is not advisable to mix two asphalts from different mines, as for instance, Val de Travers and Seyssel. Such mixtures will last for two, three, or even four years, and then break up, at least this has

been the Author's experience in the Rue de Richelieu. Seyssel rock contains less bitumen than Val de Travers, and the limestone being harder and of finer grain is frequently unimpregnated; for these reasons Seyssel rock should be broken in pieces and hand-picked before grinding. The Author has laid many streets in Paris in Seyssel asphalt, and always uses it for courtyards. In spite of the comparatively small proportion of bitumen, this rock will bear a good heating. The bitumen is not of an easily evaporative character. (See analysis, Appendix A.) Sicilian rock, from Ragusa, is a coarse-grained spongy limestone of unequal impregnation. The bitumen is of a very volatile character. This rock is no longer included in the list of those specified by the Paris engineers. (See analysis, Appendix A.) Auvergne rock contains a large proportion of excellent bitumen, but the impregnated stone is more of a grit, or sandstone, than limestone. A trial was made in the Rue du Faubourg Poissonnière, in the year 1877, and the road lasted just three months. The asphalt was compressed cold with a 30-ton steam roller, having been previously sprinkled with volatile shale oil. Auvergne mastic is coarse and sets soft. Maëstu rock has been used successfully for mastic, but utterly failed when laid in 1871 in London, in the shape of bricks compressed cold. (Appendix A.) Chieti rock is exceedingly rich in good bitumen, but has not been successfully used for compressed purposes in France. It makes very coarse mastic. Lobsann rock is of a mixed character, containing a large proportion of good bitumen and bituminous oils. It has been used exclusively in Paris since January 1878. The winter of 1878–9 was eminently unfavourable to this rock. Some new work, laid on cement foundations, and where there is little traffic, has stood fairly, but time is required to test it. If it breaks up within three years it is of little use as a contractor's material. In Paris this rock, owing to its richness in bitumen, is mixed with one-third poor asphaltic rock ground fine. (See analysis, Appendix A.)

Mastic Asphalt.

The surface of footpaths in mastic asphalt in Paris alone, is 3,150,000 square mètres,—or nearly 4,000,000 square yards; and when the courtyards, cellars, &c., are counted it is considered that double the surface exists.

The Paris engineers have made it a rule that the thickness of the layer of gritted mastic should be 15 millimètres, or $\frac{5}{8}$ inch, and a lime concrete 10 centimètres, or 4 inches thick, of which 2 centi-

mètres, or $\frac{15}{16}$ inch, are mortar floated to keep the surface level. One-fifteenth part has to be laid fresh annually. The contractor is paid for this and all the repairs besides (*i.e.* to keep the work in order), a fixed sum of 35 centimes per mètre, or 2¾*d.* per square yard per annum; the openings for gas and water pipes being paid for separately. Each system must be judged by its result. In Lyons, and in other towns of France, where repairs are paid for by the square mètre, and the thickness of the asphaltic layer is $\frac{13}{16}$ inch, the work is well done, whereas in Paris the footpaths seldom look well. In fact, the engineer, knowing that a fresh fifteenth has to be laid every year, thinks that he will comprise therein all the bad work; and the contractor does not care to do good work because he may in the following year have to relay the new work as fifteenth part, owing to changes of level, &c. Again, in this system of a limited sum paid per yard per annum for an unlimited quantity of repairs, one of the contracting parties must get an unfair advantage.

Concrete for Footpaths.

In the Author's opinion, a layer of 4 inches of hydraulic lime concrete on a firm soil is a good foundation for mastic asphalt; or for the same purpose 3 inches of Portland cement concrete may be employed. Roman cement should never be used in concretes for mastic asphalt, nor stone lime. Both cause bubbles and blisters, which eventually produce holes. Mortar floating should be used sparingly to fill up interstices in the concrete, and to form a level surface, and should be spread before the concrete is dry. A thick layer of mortar serves to cover bad concrete, but not to make a good foundation. One of the chief causes of cracks and depressions in the compressed asphalt roadways of Paris is from spreading a thick layer of mortar over the concrete, which crumbles under the traffic, and indeed under the iron rammers during the compression of the powder. A favourite fraud of the dishonest contractor is to cheat in the thickness of the concrete, nor does he neglect to carry out the same idea with the asphalt. In 1872 the Author found a considerable portion of the concrete of the Rue de Richelieu 2¾ to 3 inches thick, instead of 4 inches, and the subsoil loose (the work had been let out to the workmen by the piece), whilst some footpaths in front of the Hôtel de Ville were not laid with concrete at all, but a little mortar had been spread on the bare earth. Asphalt in itself has no more power of resistance to vertical pressure than sheet lead or india-rubber; therefore it must yield unless well supported from beneath.

Manufacture of Asphalt Mastic.

The rock must be ground into fine powder, all coarse grains being sifted out, returned to the disintegrator and reground. After being mixed with the bitumen, as described, it must be well worked, *i.e.*, the bitumen must be thoroughly incorporated with the asphalt, and an amalgam made capable of being ground again into powder. The quantity of bitumen to be added depends upon the amount contained in the rock, but 15 per cent. of the total weight is what mastic should hold when run in blocks. It is sufficiently tested when a wooden spatula can be put into the mass and withdrawn without adherence. Mastic made from fine-ground powder, when remelted, pure, or unmixed, spreads out under the wooden stave or spatula used by the asphalters for the covering of vaults, fillets, &c., and will absorb the maximum of grit when used for footpaths, stables, courtyards, &c.

Mastic Asphalt in Military Engineering.

In the many large new forts constructed in France since 1871 pure mastic asphalt has been extensively used for covering the roofs of vaults, casemates, and powder magazines, with very satisfactory results; as when the inevitable settlements of the new masonry happens, the asphalt yields without cracking, whereas cement cracks and lets the water into the joints of the masonry, causing damp in the casemates and bad health to the garrison. The most recent practice is to lay pure mastic asphalt $\frac{5}{8}$ inch thick in two layers; when applied vertically for chimneys and air shafts a recess is cut in the masonry, into which the asphalt is run, so that the water passes over to the gutters or drains. The flooring of the casemates is laid with gritted mastic. The troops in garrison have sometimes complained of the asphalt flooring being damp. It is certain that it is non-absorbent, and therefore the condensed moisture remains visible and must be mopped up or swept away. The flooring of powder magazines is in pure mastic, over which, in some cases, wood planking, fastened with copper nails, is laid.

Grouting for Granite Sets.

This work, which is charged in the Paris Architects' Price-book for sets, say 6 inches by 10 inches and 2 inches deep of mastic, costs about 2*s*. 11½*d*. per superficial yard, whereas in gas-tar and

chalk the cost is only 1*s.* 8½*d.* Mr. G. F. Deacon, M. Inst. C.E., has shown the inconvenience of using inferior materials for grouting. It is good policy to use natural asphalt mastic for this work. The interest on the increased cost is less than the cost of renewals, to say nothing of the annoyance to traffic caused by frequent repairs. This grouting is particularly useful in courtyards and stables; it prevents the effluvium from all ordinary joints, which, with the subjacent layer of sand, soon become filled with horse-dung and other filth. It also holds the sets together, prevents the edges wearing, and lessens the noise whilst improving the appearance. Natural asphalt can be melted again and again with the admixture of fresh purified bitumen, without losing its qualities. In some grouting recently carried out in front of the terminal station of the Eastern railway in Paris, the joints are run too deep to keep the horse urine out, but it cannot percolate to the subsoil. Asphalt grouting should always be laid in dry weather, and the joints well rammed, so as not to use more mastic than necessary.

Vertical Application of Asphalt Mastic.

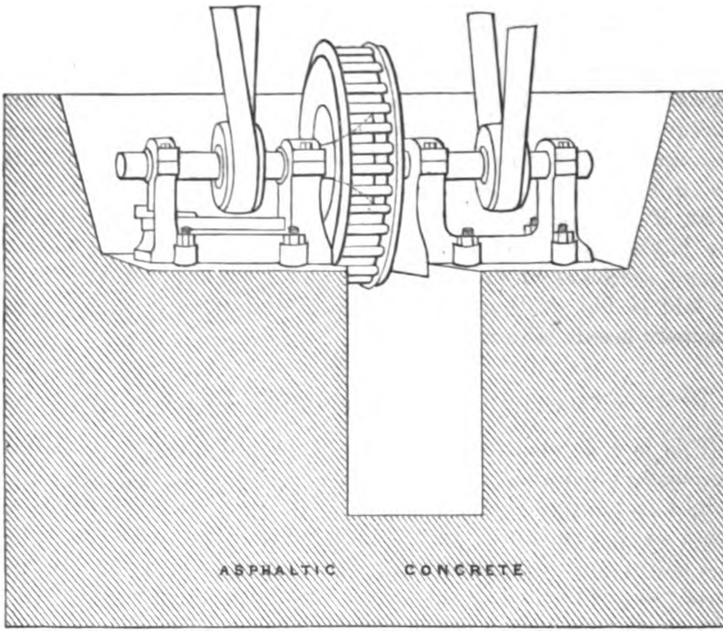
This is a development of the fillet generally employed in all horizontal applications, and to keep out damp and moisture; the height is mostly 3½ feet to 4 feet. The price paid in Paris is about 4*s.* per superficial yard ⅛ inch thick. The mastic is pure, and is laid on in two layers, one workman following the other as closely as possible, using the mastic very hot and pressing it hard. The powder magazines in the Cherbourg forts have been recently so treated; also the chimneys and air shafts of the casemates of the Paris forts. The advantages of the employment of asphalt under such circumstances are that, should there be a settlement of the masonry, it does not crack like cement. In case of leakage, the removal of 40 feet of earth is costly, and as old cement cannot be used over again, it has to be carted away.

Bituminous or Asphalt Concrete.

In 1872 the proprietor of a factory for painting on glass and china, threatened to take proceedings against the Author for damages caused by the vibration of a Carr's disintegrator, running at 500 revolutions per minute, used in pulverising asphalt in the factory of the Compagnie Générale des Asphaltes. This vibration also interfered with the counting-house work of the

Company's clerks, and, in fact, when the machine was running the ground shook within a radius of 25 yards. The old foundations in wood and masonry were therefore replaced by bituminous concrete, as were also the walls and the bottom of the pit on which the disintegrator works (Fig. 2). This succeeded so well that

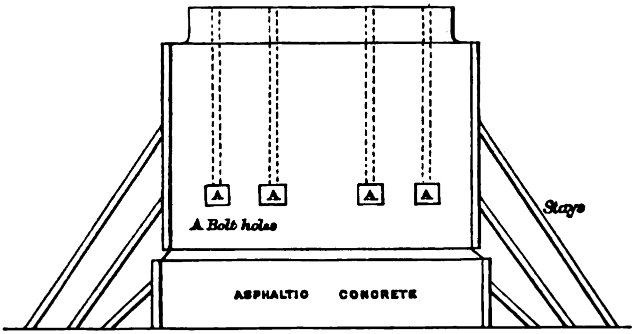
Fig. 2.



it is now impossible to know from the vibration when the disintegrator is at work, and there have never been any yielding, settlement, or repairs, since it was laid. Subsequently the Author put down a foundation for a large steam press for stamping out iron frames, and striking twelve blows per minute. Also one at the Artillery Factory in the Donjon, at Vincennes, under the orders of Captain Naquet, for a small steam hammer, and for the factories of the Paris, Lyons, and Mediterranean railway, under the orders of the Engineer-in-chief Duboys, and other similar works. At the Paris Exhibition of 1878 a block of this material, weighing 45 tons, was used as a foundation for a Carr's disintegrator for grinding flour, running at 1,400 revolutions per minute. Fig. 3 shows the most approved mode of laying a foundation for a steam hammer. For the 45-ton block an oaken framework was first made of the required, and the places marked for the bearings, recesses,

&c., surrounded by a rough caissoon in planking, firmly supported by stays from the outside to prevent bulging. A layer of hot gritted-asphalt mastic was then poured on the floor and

Fig. 3.



covered successively with a layer of flint stone and rubble, perfectly dry, next a layer of mastic, followed by a layer of flint and rubble, and so on till the top was reached. The whole was then left ten days to cool and settle. At the end of that time the surface was dressed with mastic and the planking removed. Earth was finally filled in to the required height all round, and the machine fixed and started. At the close of the Exhibition it was found impossible to break up this material, and, as blasting could not be allowed, the block remains in the ground of the Champ de Mars opposite the École Militaire. The proportions were 60 per cent. flint and rubble and 40 per cent. gritted mastic.

Imitation Asphalt.

There are two kinds of imitation asphalt: 1st. A mixture of ground limestone, ground slate, and Trinidad bitumen, which, if properly made, is as dear, or dearer, than the real article, without being one-half as good. 2nd. A mixture of ground chalk, fire-clay, and gas-tar, which is frequently passed off as real asphalt. The Author's experience of this material is that it becomes soft in summer and cracks in winter, and should never be used for footpaths, or where there are great changes of temperature. The Paris engineers, after repeated trials on account of its cheapness, have proscribed its use. This mixture is readily recognised by its dull, black appearance, its characteristic smell, and the hard metallic sound it gives when struck against iron in cold weather. The unpopu-

larity of asphalt with many engineers and architects arises from their having had work done with preparations of gas-tar improperly called asphalt. Some contractors substitute shale grease or pitch from suets, or Stockholm tar, for bitumen. The result is a soft surface for the first year, which gives off oils by evaporation, and breaks up after two or three years' wear; whereas asphalt properly laid on a good foundation will wear down evenly until little more than a film remains.

The tricks of the small Paris contractors are many. They keep a little natural asphalt and bitumen beside their boilers for show, all the while using gas-tar and chalk, so that when the work breaks up the superintendent is frequently ready to affirm that asphalt was used, and declares for ever after that asphalt is of no use.

In conclusion, the Author desires to express his acknowledgments to M. Alphand, Director of Public Works of Paris, M. Vaissière, Chief Engineer, M. Allard, Chief Engineer, M. Barabant, Engineer, M. Vauthier, Municipal Councillor, Paris, Messrs. Durand-Claye and Hervé Mangon of the École des Ponts et Chaussées, M. Mascart of the Bureau Central Météorologique, and to M. Dumas and M. Deval, Conductors of the Ponts et Chaussées.

The Paper is accompanied by a series of diagrams, from which the woodcuts have been engraved, by several specifications, and by a schedule of prices relating to the maintenance of the footpaths and pavements in Paris, which are preserved for reference.

[APPENDIX.

APPENDIX A.

I.

Extract from the Registry of Assays.

(*École des Ponts et Chaussées Laboratory.*)

Analyses of asphalts submitted by Mr. Delano, manager of the Compagnie Générale des Asphaltes, 117 Quai Valmy, Paris.

	1. Val de Travers (Switzerland) Asphalt.	2. Lobsann (Alsace) Asphalt.	3. Maëstu (Spain) Asphalt.	4. Sicilian (Ragusa) Asphalt.
Water and volatile matters at 100° Centigrade	0·35	3·40	0·40	0·80
Matters soluble in sulphuret of carbon (bitumen)	8·70	11·90	8·80	8·85
Sand	0·60	3·05	57·40 [1]	0·60
Fine or combined silicate	..	..	11·35	..
Sulphur	0·08	4·99	trace	..
Iron combined with sulphur	0·21	4·44	..	..
Alumina and peroxide of iron	0·30	1·25 $\{Al^2O^3, Fe^4O^3\}$	3·35, 1·00	0·90
Lime	49·50	38·90	5·70	49·00
Magnesia	0·10	0·15	3·85	0·45
Carbonic acid and waste	40·16	31·92	8·15	39·40
	100·00	100·00	100·00	100·00

Sample No. 1 is an almost pure limestone impregnated with bitumen. It is asphalt in the proper sense of the word.

Sample No. 2 is also composed of asphalt. It does not contain any appreciable quantity of clay as was presumed; but there is found therein 9½ per cent. of pyrites or bisulphuret of iron. Pyrites may become the cause of failure in the use of this material, by the heating to which the material is subjected in its preparation, one half of the sulphur may become transformed into protosulphuret of iron, an oxidisable matter which by exposure to the atmosphere becomes a soluble salt, viz., sulphate of iron. Thus disaggregation may result shortly after the laying down.

Sample No. 3 is not properly speaking an asphalt. It is a silicious rock somewhat argillaceous and impregnated with bitumen. It does not contain any pyrites, and would therefore be free from the accident mentioned above.

Sample No. 4 is an asphalt almost absolutely pure.

(Signed) Durand-Claye,
Engineer-in-Chief, Director of the Laboratory.

Examined by the Inspector of the School. *Paris, 13th December*, 1878.
(Signed) H. Mangon.

[1] Siliceous sand.

The Author, who has a small laboratory for making rough-and-ready analyses, was somewhat surprised to find so small a quantity of bitumen according to the above scientific analyses; the usual proportion is 11 to 12 per cent. As regards sample No. 2, the experience of the winter of 1878–9 has amply borne out the theoretical remarks. The mixture of Lobsann asphalt wherever laid down on a time foundation, where the wet could attack it on both sides, top and bottom, rapidly fell to pieces to such an extent that its use had to be abandoned and the holes filled up by the town paviours with flint pebbles, and later on by the contractor in liquid asphalt. In September 1879, three streets in Paris were still partially in macadam, viz., the roadway of the Pont d'Auteuil and a large portion of the Cours de Vincennes, whilst large particles of soft liquid asphalt remained in the Rue de Rivoli, Rue des Petites-Ecuries, &c. On Portland cement foundations it has stood pretty well; but even then in the Place du Théâtre Français and Rue Auber it has given way in places at the top after six months' wear, and the impression formed by the Author is that, under the most favourable circumstances, Lobsann asphalt will not stand three winters owing to its spongy and impure nature. The winter of 1879–80 will probably decide whether Lobsann asphalt is to be used in Paris. Owing to the lamentable results of the previous winter only 400 square mètres of new compressed asphalt have been laid in Paris in 1879, viz., in front of the Collège Chaptal, which stands well up to the present. A large proportion of old Val de Travers has been mixed with the Lobsann rock.

Sample No. 3.—The Author has never seen compressed Maëstu asphalt in Paris; but a portion laid down on bricks in Threadneedle Street, London, in 1871, broke up shortly after being laid and was removed.

Sample No. 4.—Here theory does not accord with practice, inasmuch as the Paris engineers have removed Sicilian asphalt from their specification since 1872, and would not allow the Author to use 1,500 tons of this material which had been brought to Paris as an experiment. The appearance of Sicilian asphalt is that of sandstone; the limestone is of a granular nature; the bitumen flies off at a moderate heat. This asphalt admits of carving like the Paris building stone, and some beautiful specimens of sculpture in this material are found in Sicily.

II.

The Author having obtained further samples asked for other analyses which follow:—

The sample of Seyssel rock was supplied by M. Malo from a particularly rich vein on the Savoy side of the Rhone.

The Bastennes bitumen layers are now partially exhausted. Salt is ordinarily found in the neighbourhood of pure bitumen.

Seven samples of asphalts and bitumens were examined as follow—

A 1. Asphalt from the mines of Seyssel (Department of the Ain).
2. " " Forens "
3. " " Chieti, Abruzzi, Italy.

B 4. Refined bitumen from Bastennes (Department of the Landes).
5. Seyssel asphalt mastic, melted with Bastennes bitumen.
6. Gas-tar or coal-tar.
7. Mastic known as imitation asphalt, composed of gas-tar mixed with ground fire-clay and soft chalk.

The analysis of these samples has given the following result:—

—	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Loss or waste by dessication	0·40	0·25	0·35	0·30	0·15	0·05	0·60
Matters soluble in sulphuret of carbon (bitumen) . .	9·10	2·25	7·75	69·35	14·05	65·70	20·65
Black matter combustible and not soluble in sulphuret of carbon . . .	..	..	..	4·50	..	33·00	18·45
Mineral matters.							
Residuum insoluble in acids	0·10	0·05	0·40	20·35	4·55	..	18·05
Alumina and peroxide of iron	0·05	0·15	0·25	2·85	0·85	..	2·65
Lime	50·50	54·35	50·45	0·70	45·00	1·25	22·20
Magnesia	0·05	0·10	0·70	0·10	0·05	..	a trace
Waste in combustion . .	39·80	42·85	40·10	1·85	35·35	..	17·40
	100·00	100·00	100·00	100·00	100·00	100·00	100·00

The mineral matters contained in No. 6 are composed of a little sand and carbonate of lime.

No sulphur has been found in these various samples. According to the request made in the letter of advice, a simple means has been sought of recognising mastics made with gas-tar. When gas-tar, or No. 7 mastic reduced to powder, is placed in a glass test-tube, and any dissolvent poured thereon, either benzine, ether, acetic acid, chloroform, essence of turpentine, or even alcohol, it presents opaline reflexes of a bluish green. The same phenomenon is not produced by bitumens. If the solutions made with bitumen and gas-tar be filtered they often present analogous colours. This also results with ether, acetic acid, chloroform, and essence of turpentine. The solution of bitumen in benzine becomes brown; that of gas-tar a dark red. If alcohol is used, the filtered solution of gas-tar is always golden yellow; that of bitumen is sometimes colourless, sometimes a more or less dark yellow. In fine, the distinction is not very clear. Nevertheless greenish opaline reflexes are always observed in these filtered liquors when gas-tar is used, whereas nothing similar occurs with bitumen. The following experiment appears to give a much more precise result:—

In a tube nearly closed, containing 1 gramme of material, about 5 cubic centimètres of rectified benzine are poured, and shaken repeatedly until the benzine becomes almost black; five or six drops of the liquor are poured upon a paper filter placed over another glass tube, and the filter is removed. These drops are diluted with about 5 cubic centimètres of fresh rectified benzine, and an equal quantity of alcohol at 85° of Gay-Lussac's alcohometer is added thereto. The contents of the tube are then shaken quickly and allowed to settle. The liquid soon separates into two distinct layers, the upper is benzine strongly coloured by the dissolved matter, the lower layer is formed of alcohol. This alcohol is coloured golden yellow by gas tar, and is hardly coloured at all by bitumen, or at any rate only shows a scarcely perceptible straw-coloured tint. The yellow

colouring is plainly visible when a mixture of the two substances is treated, even when gas-tar only enters for one-tenth part. This process has succeeded with all samples sent to the laboratory up to the present.

It has been tried with vegetable Stockholm tar. This tar colours all the solvents a mahogany red, but when it has been sufficiently heated to make it lose its volatile parts, and bring it to a state of dry pitch, it comports itself in the same way as gas-tar.

It would be interesting to continue these researches with Trinidad bitumen and other substances.

(Signed) DURAND-CLAYE,
Engineer-in-Chief, Director of the Laboratory.

Examined by the Inspector of the School. *Paris*, 15*th January*, 1879.
(Signed) H. MANGON.

III.

On the 1st of May, 1879, the Author received a further communication from M. Durand-Claye, of which the following is a translation:—

PROCESS FOR ENABLING THE DISTINCTION TO BE MADE BETWEEN GAS-TAR AND NATURAL BITUMEN.

The material is digested in sulphuret of carbon and filtered. The filtered liquor is evaporated dry, and heated until it becomes, by cooling down, hard and brittle like gas-tar. It is arranged so that about 1 gramme of the residuum is left. The powder thus obtained is crushed in a mortar and operated upon. A decigramme of this powder is weighed out and placed at the bottom of a closed tube; 5 cubic centimètres of monohydrated sulphuric acid are added. The tube is then closed with a stopper, and the contents allowed to digest for about twenty-four hours, when 10 cubic centimètres of water are added. This last operation must be performed with precaution on account of the great heat developed during the mixing. The tube should be placed in a vessel of cold water, and the 10 cubic centimètres of water added with a "pipette," letting it run slowly down the sides of the tube; then with a glass rod it must be gently and repeatedly stirred, leaving an interval of about one quarter of an hour between each stirring. When the mixture is finished it is thrown on a paper filter stretched over a funnel placed on a phial of 150 to 200 grammes capacity; when all the liquor has passed through, which sometimes takes a long while, it is washed with about 100 cubic centimètres of cold water. The liquor thus obtained is colourless, or scarcely coloured, if natural bitumens have been operated upon; but on the contrary it is of a dark brown colour if gas-tar has been used. If gas-tar and bitumen are associated intermediate shades are obtained. The intensity of these shades serves to indicate the approximate adulteration of the mixtures if the same conditions are observed in all cases. It is only necessary to compare the results with those obtained previously on known quantities. To compare the colour, the best way is to pour equal portions of the solution in glass tubes of the same diameter, and hold them up to the light to examine their degrees of transparency.

(Signed) DURAND-CLAYE,
Engineer-in-Chief, Director of the Laboratory.

APPENDIX B.

Table I.—Roadways laid in Compressed Asphalt from the Seyssel and Val de Travers Mines, from 1872 to 1878 inclusive, by the Author for the Compagnie Générale des Asphaltes de France, Limited, under the Superintendence of the Paris Municipal Engineers.

Date.	Names of Streets or Places.	Asphalt Thickness.	Asphalt Surface.	Thickness of Concrete. Lime.	Thickness of Concrete. Cement.	Observations.
1872		Ins.	Square mètres.	Ins.	Ins.	
May	Rue d'Antin . .	2	690	..	6	Newcastle Portland cement, has needed no repairs.
Sept.	Place du Théâtre Français, streets A and B . .	1⅝	599	4	..	Has been nearly all relaid in Lobsann powder, owing to change of level and construction of Avenue du Nouvel Opera.
Nov.	Rue de la Cité .	2	3,121	4	..	A good many repairs since 1878, owing to subsoil settling. Heavy traffic.
1873 May	Rue d'Uzès . .	2	1,150	..	..	Laid on an old macadam road, picked and levelled with a floating; has stood well; traffic inconsiderable; no omnibuses.
June	Place de l'Opera .	2	486	..	..	Same foundation as above; laid in Seyssel; traffic considerable; has been changed owing to new level.
Aug.	Marché aux Fleurs	1⅝	522	4	..	Has stood well; little traffic.
July	Rue St. Jacques .	2	173	4	..	Narrow street; much traffic; has been repaired occasionally.
"	Rue du Faubourg St. Honoré, opposite St. Philippe du Roule.	2	936	4	..	Very heavy traffic; has been relaid in 1879 in Lobsann powder, in accordance with Paris system of relaying $\frac{1}{15}$th part annually.
"	Rue Grenelle St. Germain, between Rues Bourgogne and Casimir Périer.	2	565	4	..	Heavy omnibus traffic; has been frequently repaired.
	Same street, No. 44	2	211	4	..	" "
	Same street, Nos. 77 and 79 . .	2	355	4	..	" "
1874 June	Rue Turbigo . .	1⅝ 2	916 250	.. 4	.. ..	Heavy traffic; has been partially relaid owing to tramway being laid down centre of road.
July	Rue St. Honoré, between Rues d'Alger and Castiglione . .	2	796	5	..	Heavy omnibus traffic; has had occasional repairs.

TABLE I.—*continued.*

Date.	Names of Streets or Places.	Asphalt Thickness.	Asphalt Surface.	Thickness of Concrete.		Observations.
				Lime.	Cement.	
		Ins.	Square metres.	Ins.	Ins.	
1874 Aug.	Quai de la Cité, up stream .	$1\frac{5}{8}$	66	..	..	Crossings laid upon macadam with lime mortar floating; heavy traffic; occasional repairs.
"	Quai de la Cité, down stream .	$1\frac{5}{8}$	32	..	..	
July	Rue de Vaugirard (Luxembourg) .	2	1,004	4	..	Replacing roadway in mastic asphalt mixed with iron filings; has been occasionally repaired; traffic heavy; omnibuses and flour loads.
"	Rue de Presbourg	2	149	4	..	Gutters on each side roadway.
Aug.	Rue de Grenelle, No. 79 . . .	2	774	4	..	Heavy omnibus traffic; occasional repairs.
June	Rue de la Trinité	2	434	..	4	Roman cement; behind the church, little and light traffic.
1875 Aug.	Rue de Birague .	2	60	4	..	Under archway to prevent vibration; no repairs.
Nov.	Rue Radzivill .	$1\frac{5}{8}$	583	..	4	Roman cement; alongside Bank of France; little and light traffic; no repairs.
April	Boulevard des Invalides, No. 39 .	2	128	6	..	Crossing near church of St. Francis Xavier; little traffic; few repairs.
June	Rue de l'École de Médecine . .	2	481	4	..	Replacing wood pavement; mineralised beech sets laid on lime concrete; ordinary traffic; no repairs.
Jan.	Avenue d'Antin .	2	44	4	..	Carriage entrance to avoid vibration; no repairs.
July	Parc Monceaux .	$1\frac{5}{8}$	40	4	..	" "
June	Rue Laval . .	2	996	..	4	Roman cement; heavy traffic; few repairs. The inhabitants of the street, chiefly artists, paid half the expense of transformation from granite sets.
Sept.	Rue de Faubourg St. Martin, in front of Mairie of 10th arrondissement . . .	2	333	..	4	Roman cement. Replacing wood pavement; mineralised beech on lime concrete; heavy traffic; no repairs.
1876 Aug.	Rue Vivienne .	2	905	6	..	Has stood well; no repairs. Concrete was laid in dry weather, and had a better chance than lime concrete generally.
Sept.	Place Dauphine .	$1\frac{5}{8}$	3,845	..	..	Laid on macadam with hydraulic lime mortar floating; one half surface near left side of Seine in Val de Travers asphalt, other half in Seyssel; very little traffic; has stood well.

TABLE I.—*continued.*

Date.	Names of Streets or Places.	Asphalt Thickness.	Asphalt Surface.	Thickness of Concrete. Lime.	Thickness of Concrete. Cement.	Observations.
		Ins.	Square mètres.	Ins.	Ins.	
1876 Oct.	Avenue Victoria .	2	1,020	4	2	Roman cement concrete on top of lime; has stood well; much omnibus traffic.
„	Rue St. Martin, in front of Arts et Métiers . . .	2	600	4	2	„ „
„	Rue Ville du Temple . . .	2	630	4	2	„ „
Nov.	Rue St. Antoine, corner of Rue Castex . . .	2	402	4	2	„ „
Aug.	Rue de Vaugirard, corner of Rue Cassette . . .	2	367	6	..	In front of ecclesiastical school; has stood well.
„	Parc Monceau .	1⅝	28	4	..	Gate entrance; little traffic.
Sept.	Place Ville l'Evêque	2	700	4	..	A layer of flint pebbles was laid between the concrete and the earth to avoid expense. The work has stood well; there is little traffic; it is behind the Ministère de l'Intérieur.
Dec.	Rue Roquépine .	2	606	4	..	In front of schools. The asphalt was laid in one day; has stood well, but has had many gas cuttings.
1877 July	Rue St. Louis en l'Ile	2	927	4	2⅝	Roman cement concrete on lime; has stood well, traffic fair, but no omnibuses.
Sept.	Rue de Rivoli, in front of Hôtel du Louvre . . .	2	3,431	6	..	Half paid for by householders; very heavy traffic. The Val de Travers asphalt is a little wavy in parts, perhaps from excess of bitumen or insufficient heating. A lime mortar floating ⅜ inch thick was spread over the lime concrete after it had set.
„	Rue Marengo . .	2	842	6	..	Has stood perfectly well; no waves; less traffic than Rue de Rivoli. Half cost paid as above.
„	Pont de la Butte-Chaumont . .	2	2,963	..	2	On macadam roughed with the pick; covered with Roman cement concrete; is in perfect order; heavy coal, iron, and stone traffic.
Nov.	Place du Parvis de Notre Dâme .	2	7,439	..	..	On macadam with floating on Roman cement mortar. The Parvis in Seyssel, the rest in Val de Travers. The work has stood perfectly well without repairs.
„	Rue d'Arcole . .	2	356	..	..	
„	Quai Napoléon .	2	1,456	..	..	

TABLE I.—*continued.*

Date.	Names of Streets or Places.	Asphalt Thickness.	Asphalt Surface.	Thickness of Concrete. Lime.	Thickness of Concrete. Cement.	Observations.
1877		Ins.	Square mètres.	Ins.	Ins.	
Nov.	Rue Charlemagne	2	356	4	2⅜	In front of the college; has stood perfectly.
Dec.	Church of St. François Xavier	1⅝	95	4	..	Passage leading to church; has stood perfectly.
"	Church of Notre Dâme des Champs	2	158	4	..	Carriageway in front of porch; has stood perfectly.
Aug.	Rue Rossini and Rue Le Peletier	2	421	4	..	Half expense paid by householders; has stood perfectly.
Nov.	Rue Rossini . .	2	414	4	..	Facing the Hall of the Commissaires-priseurs; has stood perfectly well.
1878 Sept.	Cité Trévise . .	1⅜	1,059	..	..	On old lime concrete covered with Portland cement mortar, in Seyssel asphalt; laid at the entire expense of the householders; has proved an excellent piece of work; with the light traffic will last indefinitely (laid under the superintendence of M. Duttenhofer, architect).

TABLE II.—THE FOLLOWING ROADWAYS in COMPRESSED ASPHALT WERE LAID in the SUBURBAN DIVISION of PARIS.

Date.	Names of Streets or Places.	Asphalt Thickness.	Asphalt Surface.	Thickness of Concrete. Lime.	Thickness of Concrete. Cement.	Observations.
		Ins.	Square mètres.	Ins.	Ins.	
1873 May	Avenue d'Jéna .	1⅝	60	4	..	Doorway passage.
1874 July	Rue des Moines .	2	192	4	..	The concrete was laid on sand; the work did not stand well; eventually a thicker concrete was laid, and the work has stood fairly since; traffic very heavy.
1875 June	Église des Batignolles . . .	2¼	385	..	..	Portland cement in parts, the rest on old macadam with Portland cement mortar floating; replaced macadam on account of excessive cost of the latter. Work has stood perfectly; heavy traffic.
"	" "	2	826	..	6	

TABLE II.—*continued.*

Date.	Names of Streets or Places.	Asphalt Thickness.	Asphalt Surface.	Thickness of Concrete.		Observations.
				Lime.	Cement.	
		Ins.	Square metres.	Ins.	Ins.	
1876 Mar.	Rue de Sèvres .	2⅛	845	..	4⅝	The street was entirely relaid on account of the tramway passing through it; but previously to that a portion of the Roman cement concrete gave way.
„	Rue Amelot .	2	336	..	4	Has stood well; laid in front of parish schools.
April	Rue de Vaugirard, No. 135 . . .	2	588	6	..	Laid alongside the Necker Hospital; has stood well.
June	Rue de Bercy .	2¼	1,003	..	6	This was not a new work, but the renewal of an old one, on a lime foundation which could not be kept in order. The wine traffic of Paris passes through this street. The foundation was relaid in Bazley White's Portland cement, and has given no trouble since.
July	Rue de Sèvres .	2	827	9	..	In front of Necker Hospital; stood well, but relaid owing to passage of tramway.
Sept.	Rue de Chaillot .	2	155	6⅛	..	In front of church; has stood well.
„	Boulevard Rochechouart . . .	1⅜	547	6	..	In front of the Collège Rollin; traffic very heavy: cost the contractor much in repairs, foundation not proving solid.
1877 April	Place St. Ambroise	1⅝	910	..	4	In front of church; the asphalt was laid in one day; has never given any trouble; traffic light.
Aug.	Avenue Daumesnil	2	509	4	..	In front of the Mairie of the 12th arrondissement; not much heavy traffic; has stood well.
Nov.	Rue Legendre .	1⅝	150	6	..	Very heavy traffic; Portland cement foundation necessary refused by Town; lime concrete never set properly; constant repairs. The only way to make the street hold is to put down a layer of 9 inches of Portland cement concrete.

APPENDIX C.

SERVICE for CLEANSING the COMPRESSED ASPHALT ROADWAYS of the CITY of PARIS.[1]

1. Organisation of the gangs .	The gangs consist of a ganger and ten scavengers, who are looked after by one foreman for every three gangs, and one inspector for every five or six gangs.
2. Area kept in order by each scavenger	About 500 square mètres.
3. Means of control	The gangers, foremen, and inspectors.
4. Working hours	4 A.M. to 4 P.M., and extra hours if necessary.
5. Tools used	Birch broom, scraping spade, hose, and squeegee.
6. Carts employed	One one-horse cart for every three gangs, to cart gravel long and short distances, and carry away rubbish.
7. Quantity of gravel sprinkled over a square mètre of surface.	In ordinary weather 1 cubic mètre for 2,000 square mètres of surface, but in snowy and frosty weather ten times the quantity must be allowed.
8. Volume of gravel heaps or stores, and distance between each.	Each heap or store consists of 1 cubic mètre, about 300 mètres apart. In the large and important streets these gravel heaps are deposited alongside the footpaths; in the narrow streets the gravel is lodged in holes (called gravel stores) covered with a wrought-iron lid.
9. Wages	Ganger, 1st class . 125 francs per mensem. „ 2nd „ . 120 „ „ Foreman, 1st class . 150 „ „ „ 2nd „ . 135 „ „ Scavenger . . . 105 „ „ Not including Sunday work and overtime, paid extra when necessary. Inspector, 1st class . 3,000 francs per annum. „ 2nd „ . 2,200 „ „ Sundays included, but not overtime.
10. Is a mechanical sweeper employed?	Not for asphalt, except in times of ice and snow, and after a heavy sprinkling of gravel.
11. How do the scavengers manage to keep the compressed asphalt roadways perfectly clean at all times, notwithstanding changes of weather and temperature?	With the squeegee when it rains; with a scraping spade or spatula when it is greasy; with the birch broom and water hose in dry weather, and also by means of an occasional flushing—say three times a week in the early morning before the traffic commences, the water being pushed off by the squeegee.

[1] Communicated to the Author by the authorities of the City of Paris.

12. How is the sprinkling with gravel effected?	In ordinary weather the gravel is sprinkled by hand taken from a spadeful, and cast in small quantities as soon as the asphalt begins to get greasy, as it will do in foggy or misty weather. In times of frost or snow the gravel is cast with a spade in quarter spadefuls, and is carried forward in a wheelbarrow by the scavenger.

APPENDIX D.

Asphalt Cubes used as Pitchers or Sets.

In 1872 the Author, finding a patent (Robin and Malo) for asphalt sets compressed cold in iron moulds, to a pressure of say ½ cwt. to the square inch, laid an area of 4 mètres square 2 inches thick, in the Cours de Vincennes, Rue Richer, and Champs Elysées. The sets were laid close together on the old compressed asphalt, and were surrounded with hot compressed powder. Under the traffic they appeared to join and make a smooth surface.

In 1873 the Author purchased a large dry-earth brick-making machine, and proceeded to make asphalt bricks under the inspection of M. Vaissière, chief engineer of the first division of Paris. It was soon found advisable to use hot powder instead of cold; also that the bricks had a much greater breaking strain after three days than on leaving the mould. The machine broke so often that it was abandoned. There may be an application for these bricks where powder cannot be employed, and where they can be supported laterally. A sample laid under these conditions in 1875, at the machinery stores of Mr. T. Pilter, 29 Rue Alibert, Paris, subject to an enormous daily traffic of heavy goods, has never stirred. Well compressed asphalt can be sawn with a handsaw like wood.

Mr. Delano. Mr. W. H. Delano desired to ask why gas and water pipes were buried under the roads. The subject was a sore one with roadmakers. He had once laid a road which was broken up four times before twelve months had expired. Seeing that gas and water pipes, telegraph wires, and the like, were all buried, it was strange that the different companies did not come to an understanding as to the time when the roads under which they were placed should be taken up. The placing of such things in the roadway was a great annoyance, not only to the roadmakers, but to the public. A greatly improved system had been adopted by Mr. Haywood at the Holborn viaduct, where the pipes were put in a gallery, and Sir Joseph Bazalgette had carried out subways in the Thames Embankment. It would be interesting to know if any bad results had arisen from this plan. With reference to the objection to asphalt, on the ground of slipperiness, the remedy was to be found in good scavenging. He had received a letter from the manager of the omnibus company in Paris (a company possessing twelve thousand horses and a large number of vehicles) recommending the Charlier system of shoeing, which was well known in England amongst veterinary surgeons and roadmakers. If asphalt could be employed in the courts and narrow roadways of large cities, where so many poor children were poisoned by the vitiated air and filth, he believed the result would be very advantageous. He hoped that analyses would be made of the air over asphalt roadways as compared with roadways laid with sets. The scavenging in London was very bad, and a person coming to the metropolis, after an absence of some years, could not help noticing it. He was surprised to see the roadway in front of Buckingham Palace in a vile condition. Of course, as asphalt was impermeable, it had to be cleansed, there being no deodorising principle in it, as partially existed in macadam, before saturation. It would be observed that no remarks had been made in the Paper as to the comparative cost of asphalt and macadam. In Paris it was rather difficult to get the information, but he had ascertained that the cost price of macadam, including steam-rolling, was 6 francs 30 centimes per square mètre. The maintenance, however, of a macadamised road might reach the enormous sum of 17 francs per square mètre per annum; that was the case in such places as the Champs Elysées and the Rue Royale, where there was a heavy traffic. But the cost of macadam did not end there; it formed banks in the river, and at present steam-dredging was employed to remove the banks of sand in front of the drains in Paris. He had a report by M. Vauthier, civil engineer, and a member of the

Mr. Delano.

Municipal Council of Paris, from which it appeared that the maximum cost of granite was 22 francs per square mètre. The mean cost of the Paris roadways, extending over 6,000,000 square mètres, was 17 francs, the mean cost of their maintenance being 1 franc, not including scavenging nor interest upon outlay in any case. In narrow, crowded thoroughfares, the cost of maintenance was, he believed, 3½ or 4 francs. The chairman of the Paris Cab Company stated that the traction on asphalt was much less than on any other system of roadway. The manager of the Omnibus Company corroborated this opinion, and considered that the wear and tear of carriages, horses, harness, &c., was much less on asphalt roads than on any other. With regard to the Seyssel and Val de Travers mines, of which drawings had been sent, he might mention that they contained marine shells and shark's teeth, as well as fresh-water shells.

Mr. Ellice-Clark.

Mr. E. B. Ellice-Clark had hoped that the Paper would contain some statistics as to the cost of the porphyry sets and the macadam used in Paris, and of the different kinds of material employed in London, reduced to a standard. The only figures given were as to the cost of asphalt in Paris, 13*s.* per yard, and of cleansing it, 2*d.* per yard; but, of course, without any comparison of the traffic, it was difficult to form an idea of what the expense would be in England. He had, a short time ago, taken a good deal of trouble to ascertain the cost of different kinds of paving. He had taken Mr. Deacon's figures for the wood paving in Liverpool, believing that they were the only reliable figures ever published, and reduced them with the other calculations to the standard of 100,000 tons per annum per yard of width, with the result shown in the following Table:—

—	Original Cost per Square Yard.		Annual Outlay.								
			Interest.	Sinking Fund 3 per cent. Compound Interest.	Maintenance.		Scavenging.		Gravel.	Total.	
	s.	*d.*	*d.*	*d.*	*s.*	*d.*	*s.*	*d.*	*d.*	*s.*	*d.*
Wood pavement . .	15	1·5	7·5	10·1	0	1·0	0	2·7	5·0	2	2·3
Val de Travers compressed asphalt .	18	0·0	9·7	..	0	3·6	0	0·4	..	1	1·7
Granite sets, 7 inches × 3 inches laid over a layer of 12 inches of cement concrete	17	9·0	9·6	0·5	0	1·3	0	2·5	..	1	1·9
Macadam in South of England . .	4	9·0	2·1	..	3	6·0	1	0·0	..	4	8·1

Mr. Ellice-Clark.

Those figures showed that if the contract entered into by the Val de Travers Company in London could be maintained, their asphalt was cheaper even than granite sets. There could be little question as to the many advantages possessed by asphalt over almost all other materials for road paving. According to his experience, compressed asphalt was the best for roadways. In the City of London, he believed, thirteen or fourteen kinds of asphalt had been tried within the last nine or ten years, and only three of them remained at present in streets with heavy traffic. It was hardly necessary for English engineers to go thoroughly into the chemical part of the question, because all that information had been reduced to practice by the actual wear and tear in the City of London. There were some curious anomalies in the behaviour of compressed asphalt to which he desired to refer. He had recently laid a footpath with that material, $\frac{3}{4}$ inch thick. In a short time a large number of cracks appeared, but the path had stood the effects of the last two very severe winters; and, although the cracks were unsightly, they did not appear to have injured the asphalt in the least. He believed the cracks were due, primarily, to the use of a cement not sufficiently purged; the concrete expanded in various directions, and the asphalt followed it, not being sufficiently elastic to extend over the fissures without rupture. Another peculiarity was that in humid weather there was a greater accumulation of dirt on the compressed asphalt than on the mastic. Perhaps the Author could state, from his experience in Paris, the reason for that peculiarity. No particulars had been given as to the amount of mud in the streets. Mr. Ellice-Clark had compiled the following Table with reference to that point:—

Material.	Load of Mud for Area.	Traffic per Annum per Yard of Width.
	Superficial Yards.	Tons.
Macadam .	344	25,000
Granite sets .	500	50,000
Wood . .	1,666	25,000
Asphalt . .	4,000	500,000

So that, as dirt meant mud in wet weather and dust in dry weather, asphalt was unquestionably a most economical paving. One of the greatest advantages possessed by asphalt for street paving was the facility with which repairs could be executed.

Cheapside had been laid with asphalt in December 1870, and the roadway had never been blocked a single day for repairs. This alone was an advantage to a city with great street traffic, which could not be said of any other kind of pavement. It would be hardly possible to overrate the importance of having streets permanently open for traffic. Again, the rapidity with which it was originally laid, compared favourably with other materials. In Paris, he believed, a given area of each road had to be opened in eight days; in London, fourteen days had been found ample time to take up the old stones and lay asphalt and concrete, and permit traffic. The Author had suggested the use of asphalt concrete costing 80*s*. per cubic yard; this was too high a price, because a bituminous concrete, composed of ballast, coal tar and creosote oil, could be laid for 21*s*. per cubic yard, 6 inches in thickness. It had been tried in Liverpool under sets with manifest success. By using a concrete of this kind the work of laying a road could be shortened by the difference in time required for Portland cement concrete to set and that required for bituminous concrete, which was a few hours only; so that a road fit for traffic might be laid in London in eight days. There was no reason why this kind of foundation should not be equal to Portland cement concrete; and it was well worth the attention of municipal engineers and asphalt companies. With regard to foothold for horses, or rather the absence of it, the City engineer had demonstrated, by a series of observations of an exhaustive nature, that asphalt occupied a position between wood and granite, in the order named; and the popular outcry against the slipperiness of asphalt arose from the greater number of horses falling at one time. He was strongly of opinion that the Author was correct when he stated that this absence of foothold was due to want of cleanliness. The City Corporation had recently put down a number of hydrants all over the City area. If these were utilised in cleansing asphalt, the falls of horses would be reduced considerably. The Author had made no allusion to the fact that during the past few years the new pavements of Paris in asphalt were much inferior to those formerly laid; it had been asserted that this was owing to the use of the Lobsann asphalt, which did not contain sufficient calcareous matter in the natural rock. Mr. Ellice-Clark.

Mr. A. Southam remarked that where it was desirable to lay asphalt on carriageways, there could be no doubt that compressed asphalt was the best for that purpose. He had paved about 25,000 yards of footway in the parish of Clapham, since 1872. Various small specimens were first laid. Then about 1,000 yards Mr. Southam

Mr. Southam. of Barnett's asphalt, 1 inch in thickness, was tried; the cost was 4*s*. 6*d*. per square yard, and it was still in existence, and might be considered a fair path. It was afterwards thought desirable to make the best footpath that could be obtained in asphalt, and, after considerable investigation, the Val de Travers compressed asphalt was selected, and more than 20,000 superficial yards of that material had been laid. A great object was to secure uniformity of paving throughout the district, also facility in executing repairs. It was somewhat unfortunate that transverse cracks had appeared about every 6 or 8 yards. They made their appearance from about three weeks to twelve months after the path was laid. Some of the cracks were cut out, when it was found that corresponding cracks existed in the concrete below. The whole piece was cut out, and new concrete put down, which was kept exposed for six or eight days to harden. Then a thin coating of mastic asphalt was laid over it, previous to the powder being restored. Similar cracks, however, appeared again in the same line, and it was difficult to account for them. He thought to some extent they depended upon the concrete. Great pains were now taken with it, and 6 parts of ballast to 1 part of cement had been substituted for 8 parts of the former to 1 part of the latter, clean Thames ballast being used; it was mixed with very little water, and was well beaten with shovels. The cement had been tested, and had broken at a pressure of 450 lbs. to the square inch after seven days, during six of which it was laid in water. The concrete for the last piece of paving was kept open for fourteen days, so that it was dry before the powder was laid upon it; the footpath was previously rolled and consolidated, and this path had shown very few cracks. He was inclined to think that compressed asphalt was scarcely so durable as had been generally supposed. The mastic asphalt he believed was somewhat harder, though it was objectionable from the uncertainty of its mixture, from the difficulty of making the repairs to match the rest of the paving, and from the furnaces for melting it having to be in the street. He had not yet decided whether it was advisable to continue the use of compressed asphalt, or to resort to the mastic. He was surprised at the immense area of footway paving laid in Paris, but the Author had not stated of what it was composed. Mr. Southam presumed that it was chiefly mastic. The Val de Travers Company had assisted him greatly by their willingness to lay the concrete in any way that might be desired, and to keep it exposed for any length of time. Their manager had suggested that lime concrete would prevent the cracking, and accordingly

one line of path had been laid with it. It was not a success; there were no transverse cracks, but it had failed from the settlement of the concrete, which was not yet hard, and had cracked longitudinally from the frost. The concrete in this instance was laid from fourteen to eighteen days before being covered with asphalt. Very few cracks had appeared in the city paths. The foundations were, perhaps, more solid, and owing to the greater traffic brought to bear upon them, the asphalt was more compressed and kept in its place. The asphalt in Clapham had suffered from cracks during the late severe winter, but they had all been longitudinal instead of transverse, and after the frost they had closed, and did not look so bad. In this district the use of asphalt would probably be largely extended if a perfect paving could be laid. He would be glad to know which was the best description of asphalt to use for footway paving. Mr. Southam.

Mr. H. C. Scott observed that as a director of the Val de Travers Asphalt Company, he might be permitted to refer to their experience of London roadways. The question of cracks upon compressed asphalt footways was one that he frankly confessed had once given them some concern; but they were of opinion that the fault would only last a short time. In going along the Cheapside pathway, which had been laid between three and four years, he had not observed any cracks; and in Moorgate Street, where it had been laid four or five years, there were very few. He had not discovered that the pavement was affected by the humidity of the atmosphere or by rainy weather. They sometimes found, when the drying process had set in, that there was a little streak through the footway, but in a day or two it entirely disappeared. On the grounds of economy, noiselessness, and cleanliness, after the many pamphlets that had been written and the many reports presented, there could be no doubt as to the superiority of asphalt; and he believed that compressed asphalt for roadways possessed greater advantages than any other material. The roadway in Cheapside had been laid ten years, and it was still in existence. The heaviest traffic in the world passed over it, but it had never been interrupted for an hour. The repairs were done early in the morning, and the result was that Cheapside possessed a clean, noiseless, and cheap roadway, which, as he knew from the shopkeepers, was regarded as an enormous boon. As to the objection on the grounds of slipperiness, that, as the Author had explained, was a question of cleansing, and not a question of asphalt. If engineers and district surveyors would impress upon the Vestries of London the importance of spending more money in cleansing Mr. Scott.

r. Scott. the roadways, they would confer an immense benefit upon the community. The condition of the lanes, slums, and alleys of London was deplorable. The rejected granite sets and York flagging from the richer districts were transported to those localities, where the children of the poor were congregated, and where they played about all day in puddles. If the authorities would only give them asphalt, they would be doing something towards making life tolerable to many who now regarded it as little better than a burden.

r. Lewis. Mr. W. B. Lewis asked if any one accustomed to lay asphalt upon concrete had ever tried the plan of laying the concrete in slabs, with joints, in order to prevent cracks. Engineers who had used concrete in large masses were aware that the difficulty of cracks frequently occurred. At the Victoria docks, in one wall 1¼ mile long, and 33 feet or 34 feet high, of solid concrete, there was a hair crack through it at about every 14 feet. He presumed that this arose from the material being homogeneous, and that there must be expansion and contraction somewhere. Possibly the cracks in the asphalt pavement arose from the concrete being laid in one continuous mass. It must yield somewhere to atmospheric influences, and consequently cracked. If it were laid in slabs, with joints ever so small at intervals, possibly that would get rid of cracks in the asphalt.

r. Giles. Mr. A. Giles, M.P., said the Author had expressed an opinion that asphalt yielded sufficiently without cracking where any settlements in masonry took place; while Mr. Southam observed, that on investigating the causes of cracks in asphalt footways, he had found them due to the cracks in the concrete underneath. Both those views could hardly be correct. If there was sufficient elasticity in the asphalt to allow of yielding when settlements of masonry took place, it ought to possess the same elasticity in footways when the concrete cracked. He had not had great experience of asphalt, but he had had considerable experience in the use of concrete. In order to overcome the difficulty referred to by Mr. Lewis—the formation of cracks where large masses of concrete were used, especially in long walls—he had lately adopted the plan of putting in perpendicular joints, instead of making one continuous wall many hundred feet or yards in length, and that had to some extent obviated the difficulty.

r. Ellice-lark. Mr. Ellice-Clark wished to say, in explanation, that in Brighton no cracks had been observed in the mastic asphalt, which contained a larger amount of bitumen; but they had been observed in the compressed asphalt, which had no foreign bitumen.

Mr. W. H. Delano remarked that the coating of the masonry was made of a mixture of asphalt powder and bitumen, containing 15 per cent. of bitumen; it was therefore much more elastic than compressed asphalt powder. He had never known compressed asphalt powder used as a coating for masonry. Mr. Delano.

Mr. John Knight said that Portland cement concrete expanded and contracted according to the weather, while asphalt, if laid in a mastic state, neither expanded nor contracted, whether ½ inch or 1 inch in thickness. It appeared that the asphalt in Brighton had not cracked because it was in an elastic state, while that laid in Hove in a compressed state had cracked. The reason for the cracking was that it was not of sufficient thickness—only ¾ inch; and the same reason applied to other cases that had been mentioned. No cracks had appeared in Cheapside or in Moorgate Street, because the asphalt had been laid of sufficient thickness—1 inch. Compressed asphalt should not be laid less than that thickness, otherwise it would crack in every direction. The first asphalt of the Val de Travers Company that he had noticed was in a mastic state. It did not last very long; it was not suitable as a mastic asphalt, but as compressed asphalt it was very good. When a surveyor saw a piece of York stone he could express an opinion as to whether it was good or bad; but he could pass no such opinion with regard to asphalt, whether in a mastic state, or compressed. The goodness of the material was only to be ascertained by its durability. The best piece of asphalt in the City was laid in a mastic state in King William Street eight or nine years ago, and it still existed as when first laid, with the exception of a few repairs for gas and water purposes. Mr. Knight.

Mr. J. Fogerty observed that he had had some years' experience, both as an architect and as an engineer, in laying pavements and in the use of asphalt and Portland cement for the covering of roofs and other structures. He did not believe that a layer of ¾ inch of asphalt of any kind was sufficient, especially in footways. The chief cause of cracks was, he thought, to be found in the concrete, and there was only one way to get rid of them—a plan that he adopted ten years ago—never to lay more than 9 feet length of concrete at once, bringing straight joints across the footpaths by inserting boards, withdrawing them when the concrete was soft, and leaving the fissures open for a considerable period. The great trouble in getting concrete laid was, to induce the workmen not to use too much water. It could not be laid too dry, especially where it had to be covered with Portland cement or asphalt. A long discussion had recently taken place at Mr. Fogerty.

Mr. Fogerty. the Royal Institute of British Architects[1] on Portland cement and concrete, and it seemed to be the general opinion that one of the chief troubles connected with concrete was the over-use of water by workmen. If it was laid almost dry, and thoroughly rammed and jointed at intervals, the joints being left open until the water had evaporated, it might be covered with asphalt without any fear of cracks, provided there was a solid substratum. But where it was laid upon clay, difficulties would invariably arise unless there was interposed between the concrete and the clay a considerable amount of hard, pounded, dry filling for drainage purposes. The most difficult pavements were those laid upon a clay substratum, and he knew of no mode of curing the difficulty except by getting out a considerable depth of clay, and replacing it by dry material. For covering roofs, arches, and the like, he preferred the mastic to the compressed asphalt. For level roadways and footpaths there could be nothing better than the compressed asphalt for pavements, on the ground of cleanliness, but the danger of horses slipping in greasy weather was a serious one. He had often passed through Cheapside in muggy weather, and seen several horses down at one time, and during the recent fogs probably as many as ten were down at once. Whether that could be obviated he did not know. The question had not been fully dealt with in the Paper, and he hoped the Author would allude to it in his reply. The only remedy that could be suggested was a thorough cleansing, which, so far as Cheapside and similar streets were concerned, could only be done during the hours of traffic by means of numerous hydrants, and the constant use of hose-pipes, with large side apertures, such as those used in Paris, to carry off the washings into drains or reservoirs. Allusion had been made to the operations of gas and water companies, which destroyed the roads and pavements in cities. Some twenty years ago the parish of Marylebone offered a prize for the best section of a subway, and it was won by a young student in the engineering class of University College—Mr. Davis. Since that time very few subways had been constructed in London, and even in those, gas and water companies were very unwilling to place their pipes. The only objection he had heard was that the escape of gas in such enclosed places would be dangerous. On that point he should be glad to hear the experience of the City surveyors who had charge of streets and subways in which gas pipes were laid.

Mr. Glenn. Mr. HENRY GLENN attributed the cracks that had occurred in

[1] *Vide* Transactions R.I.B.A., 1879–80, p. 109.

the Val de Travers asphalt to the want of a sufficient quantity of bitumen. Heating the powder drove off the bitumen to a large extent, and if the quantity was reduced, as stated in the Paper, to $9\frac{1}{2}$ or 10 per cent., cracks would be sure to occur in severe weather. In the case of mastic asphalt, the difficulty could be obviated, because the cauldron was in the street; and if the asphalt did not contain a sufficient quantity of bitumen, an addition could be easily made to it, and an experienced foreman would know what quantity to add. Some reference had been made to mastic asphalt not wearing so well as other kinds of asphalt. A good deal depended upon the size and quantity of the grit put into it. There ought not to be too much, and the size should not be too large. If it was too large, it would work out, which a small piece of grit would not do. When the Barnett Asphalt Company was in existence, it was the practice to use the large grit, and the consequence was that nearly all their work failed. He had seen concrete laid down in 6 or 7-feet lengths, and allowed to get thoroughly dry at the end; and when the next layer of concrete had been put on, it had not been sufficiently wetted and properly jointed. In such a case cracks would arise through the concrete; and if the asphalt did not contain a sufficient quantity of bitumen, it would go through to the surface of the asphalt. He did not agree with those who had said that the concrete should not be laid in long lengths. He thought the more men that were employed, the more quickly the concrete could be laid, and the longer the lengths, the better. The work was then all of a piece, and was in the best condition to receive the asphalt. Mr. Glenn.

Mr. E. J. HARRISON had under his control, on behalf of the Val de Travers Company, the majority of the asphalt roadways in the City of London. The history of the compressed roadways in London was soon told. The first that was laid was in Threadneedle Street in 1869. It consisted of a layer of 2 inches of Val de Travers compressed asphalt on a concrete foundation. He had no doubt that many members had noticed it when it was being laid, as it created a great sensation at the time. He remembered looking at it and wondering how many weeks it would last. It was now within two months of being eleven years old, and was still, as it always had been, in good condition. Some new Aberdeen granite had been laid beside it for a trial of endurance, and seven years afterwards it had got into such a state as to require redressing and re-setting; but that was not done, because, when the inhabitants of the street learned that the street was going to be Mr. Harrison.

Mr. Harrison. closed for re-paving, they expressed a preference for an asphalt roadway, which the city authorities gave them. Since 1869 the progress of asphalt roadways throughout London, though rather slow, had been steady. There were now in the City of London alone 12,000 or 14,000 lineal yards of paving, covering a superficial area of 150,000 yards. The Val de Travers Company had upwards of one hundred roads under their charge, many of them being the main thoroughfares of the city, having a concentrated and heavy traffic; and the area would be considerably increased during the present year. One noticeable feature with regard to the use of asphalt was the great number of preparations that had been tried. Between 1870 and 1880 more than fifteen had been employed in London, most of which had proved failures. His company had already replaced eight or ten of them, not always under favourable circumstances for the company. In order to shorten as much as possible the time during which the streets were closed for re-paving, the company had generally agreed to lay its asphalt upon the old concrete foundations, some of which had been almost as bad as the asphalt that had been placed upon them, while others had been damaged by the traffic passing over them after the asphalt had worn out. In main thoroughfares like those of London, where every hour's stoppage of the traffic affected not only the occupiers of the particular street, but more or less remotely the traffic of the whole of London, the use of a paving material which required constant renewals or frequent repairs was a serious matter. He certainly could claim, on behalf of the Val de Travers Company, that it had never closed a city street for repairs, and such repairs as it had done had never affected the traffic in any appreciable degree. A very little hole, if neglected, speedily became a big hole, and for their own interest, if for no other reason, they had always taken care of the little holes; the repairs, therefore, had generally been done on a small area, rarely exceeding 2 or 3 square yards, and early in the morning before the traffic commenced. The openings for gas and cuttings for water-pipes, which were generally a source of great obstruction, were less serious with an asphalt road than with any other paving material. A hole could be cut exactly the size required, and when the work was done it might be made good immediately. Moreover, leakages in mains under an asphalt road were less frequent than under any other material, on account of the absence of vibration. Still those cuttings had to be made, and frequently there was a trifling settlement of the new work, producing hollows and forming puddles, which were more conspicuous on

an asphalt surface than on any other; so that he should be glad to see the introduction of subways under the London streets. At the request of the Author, he had had small samples of the roadways cut out from some of the oldest roadways having the heaviest traffic, and they were on the table for inspection. Two of them were from Cheapside, ten years old; one was from Old Broad Street, and another from Gracechurch Street, nine years old; and one was from the Poultry, a relay which was only three years old. The roadway of the Poultry was only three years old, because the houses on the north side were set back several feet three years ago, necessitating an alteration in the footway and roadway. The company laid down new concrete where necessary, and faced up the old, and then spread asphalt on the top of it. They had good weather, and with the assistance of the authorities, and the good will of all the inhabitants, they managed to carry out the work in seventeen days. It had proved very satisfactory, and they had never had occasion since to spend a penny upon it. When Mr. Deacon's Paper on "Street Carriageway Pavements" was read and discussed,[1] very little was said about asphalt roadways, Mr. Deacon stating that he had had no experience of them, the gradients in Liverpool not allowing the use of asphalt. He had been struck with the unanimity with which every speaker on that occasion urged the necessity of a solid foundation for a good road. Asphalters were especially of that opinion. An asphalt road was in reality a concrete road with a surface of asphalt put upon it to carry out certain ends. If the concrete foundation were taken away, or tampered with, or negligently laid, asphalt itself would form a very sorry paving. In dealing with that question, one important point to be considered was the obligation under which the engineer or surveyor was placed to have the road closed for paving for the shortest possible time. For that reason his company had always urged the desirability of laying a concrete composed of a quick-setting Portland cement with the best obtainable ballast. As far as his experience went, if a lime concrete was sealed up hermetically by asphalt on the top, there was no knowing what might happen underneath; whereas, if Portland cement concrete were left open for a few days, and then covered with asphalt, engineers could form a pretty good idea of what would happen. In London they were indebted to the French asphalters for all that they had first learned as to the nature and treatment of asphalt; but Mr. Harrison.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lviii., p. 1.

Mr. Harrison. he thought that they had now beaten their instructors, putting down better work and maintaining it better. He had been struck, on a recent visit to Paris, with the condition in which some of the roads had been allowed to get. He believed that it had partly arisen from the system there adopted of requiring the contractor to take up every year, whether it was required or not, one-fifteenth of the work laid down, which he regarded as offering a premium on bad work. Another reason was the use of lime concrete with lime mortar on the top. The only failure that he knew in Val de Travers roadways had been in connection with the use of lime concrete under lime mortar in the roadway laid (after that in Threadneedle Street) in Holborn, opposite Gray's Inn. It had been laid by Englishmen, who were novices, and who followed slavishly the specification prepared by the French engineers. That specification prescribed a layer of about 9 inches of lime concrete with $\frac{3}{4}$ inch of lime mortar. When the concrete was ready to receive the asphalt, a fire broke out in Holborn, and the barriers protecting the concrete were broken down; the place was flooded with water, the engines drove over the concrete, and the population of Gray's Inn Lane trampled it down. It was subsequently made good; the asphalt was spread, and some time afterwards the Val de Travers Company succeeded by inheritance to its maintenance, and certainly it had been a "heritage of woe." For five or six years they had kept up the road at considerable expense and trouble, and at the end of that time they received the permission of the road authorities to relay the whole in two longitudinal strips, so as not to stop the traffic. On removing the asphalt it was found that the lime concrete had never set, that the mortar floating had never adhered to the concrete, but was mostly in powder, produced either by the action of the rammers, or by the traffic afterwards. They broke up the concrete, sifted out the lime, relaid the foundation with Portland cement, and put fresh asphalt on the top. That was done about four years ago, and the work had since proved satisfactory. Some of the workmen now in his employ, who had been previously engaged in Paris, had told him, that in several of the roads there the asphalt had been laid upon the existing macadam. The Author had referred to certain roadways of asphalt with granite channels. It appeared to Mr. Harrison that granite channels were superfluous. As between an asphalt roadway with a granite channel, and a granite roadway with an asphalt channel, *quâ* channel asphalt would be the preferable material. The Val de Travers Company had laid a great many footpaths in England, both in mastic and in

compressed asphalt, and he was of opinion that it was not desirable Mr. Harrison. to have the material of a less thickness than ¾ inch. Some years ago they laid ½-inch mastic footpaths, but the result had not been such as to encourage that mode of construction. It had even been adopted in some of the streets in the City of London having the heaviest traffic, such as Gracechurch Street and King William Street; but in four or five years the footpaths had become so much worn that it was thought desirable to take up the ½-inch mastic and lay down ¾-inch compressed, which had stood fairly well. He had been surprised to hear that his company had been credited with a preference for lime concretes over cement concretes for footpaths. That was far from being the case. The footpath referred to was laid as a sample under some special conditions. It was a fact, that in certain footpaths, particularly those in the suburbs, where there was little traffic, transverse hair cracks appeared from time to time. The first cracks to which his attention had been directed were in the footway round the garden in Leicester Square, and appeared six years ago. The cracks were there to the present time; they had not in any way affected the stability of the work, but they were unsightly, and he should be glad to be able to prevent them. He had noticed that the better the concrete on which the footpaths were laid, the greater the number of cracks appearing in them, and the worse the concrete the fewer the cracks; indeed, if they laid the concrete bad enough there were no cracks at all. He had found it impossible to lay a horizontal riband of good cement concrete 3 inches thick without finding a hair crack at every 10 or 20 feet. The crack in compressed asphalt followed the crack in the concrete. Of course the footpaths were not subject to that hardening effect which was produced by the rolling of wheels on roadways. He never remembered seeing a crack in an asphalt roadway, although he had little doubt that cracks might be found in the concrete underneath. Mastic asphalt being more elastic than compressed asphalt, the cracks were not so numerous in it. Nevertheless he was of opinion that, *cæteris paribus*, a compressed footpath was a more desirable one than a mastic footpath. It was pleasanter to walk upon, owing to the absence of grit; it was handsomer, and it was also cheaper to lay; moreover, it had not the disagreeableness of mastic footpaths arising from the smell of the boiling asphalt in the cauldron. With regard to the surface duration, he believed that the compressed asphalt was better than the mastic. He was not surprised that very little had been said on the subject of slipperiness in connection with

Mr. Harrison. asphalt. The matter really lay in a nutshell. Roads when dirty were slippery whether paved with granite or asphalt; but in the case of granite, a slipping horse might be pulled up by the joint of the second or third stone, whereas on an asphalt road there were no joints to prevent a fall. The true remedy was to keep the roads clean, as was done in Paris, where the asphalt road was a favourite one with cabmen and omnibus drivers. He was glad to find that, quite recently, the City authorities had arranged to have a certain number of hydrants used for washing the streets. He hoped that the experiment would be carried out carefully, and that the streets would be washed every morning before the traffic commenced.

Mr. Copland. Mr. H. S. Copland said that the Paper, although its title was "On the use of Asphalt in Engineering," dealt only with one kind of asphalt, the Val de Travers, and of its use chiefly in the construction of roads, or rather in the coating of road surfaces, which was only a small branch of a large and important subject. He maintained that asphalt was wrongly used if employed as the surface of a roadway. Engineers had to consider other things besides the cleanliness of the material and its noiselessness. As to the latter, though asphalt was free from one class of noise, it was attended with another—the clatter of the horses' hoofs, which was very irritating to persons of nervous temperament. Nor was it enough to pay attention to the durability of the road; they had also to take into account the foot-hold given to horses, and the amount of tractive effort required, not only to draw the vehicles along the road, but to start them; and they had further to consider the cost of construction, maintenance, and cleansing. In regard to cleanliness, a good asphalt road was undoubtedly the best that could be constructed, and as to its impermeability to water, thus affording a protection to the foundation, it was also an excellent material; but for slipperiness and deficient foot-hold it was about the worst road in existence. As laid by the Val de Travers company, it was exceedingly durable, but it was costly in the first instance as compared with other materials. Taking all the requirements into consideration, he had arrived at the conclusion that for the surface of a road no material was equal to wood. But in order to obtain a good foot-hold on wood, it was necessary to leave spaces between the courses, principally for the want of which the old wood-roads of twenty years ago had fallen into disuse. Other reasons for their discontinuance were that they had not been placed upon a proper foundation, and the blocks were not properly cemented or keyed together.

Mr. Copland.

He believed that the proper mode of using asphalt was to lay a damp-proof course of that material (to prevent the infiltration of water) on a foundation of concrete, and then to place wooden blocks upon the asphalt layer to take the surface wear of the traffic. The blocks were not only keyed to the concrete, but they were keyed to each other by the asphalt running into the joints, thus forming a monolithic slab of material, which afforded a good foot-hold, could be readily kept clean, and was comparatively noiseless. As such a slab extended from one side of the road to the other, the weight of the traffic was transmitted over a large area, and was not confined to one block; the road being elastic, would wear uniformly; it would not press too directly upon the concrete foundation, and particularly on one part of it, and a smaller depth of concrete would suffice. Such a surface, if the wood were properly selected, would remain perfect for a number of years. In Boulogne, four and a half years ago, he had laid down blocks only half the depth of those used in London, for a traffic exceeding 120,000 tons per annum in a street 20 feet wide. The surface was still perfect, and there were no depressions. The wear was solely from surface attrition, and had amounted to about $\frac{3}{16}$ inch per annum. The London company formed to work his English patent had laid 60,000 square yards in London roads which had not in some cases worn quite so well as the road in Boulogne in consequence of the wood not having been so well selected. The cost of such a road, fit for the heaviest traffic in Paris, would be from 12 to 15 francs per square mètre (the amount given for the road described by the Author being 17 francs), and the average cost of maintenance would not exceed 1*s.* per square mètre per annum. He therefore maintained that his road, while offering all the advantages of freedom from noise, and being a better road for traction, would cost the municipality of Paris less, over a term of years, than asphalt. With regard to slipperiness, it appeared from the report presented by Mr. Haywood to the City Commissioners of Sewers in 1873, that on granite pitching one horse fell for every 132 miles travelled. On Val de Travers asphalt one horse fell for every 191 miles travelled; and on wood pavement (not asphaltic wood pavement, but the nearest approach to it), one horse fell for every 446 miles travelled. But the nature of the falls ought to be taken into consideration. Of the total number of falls on wood pavement only one-eighth might be called dangerous, while three-sevenths of those on asphalt were dangerous. The danger was not simply from broken knees and from directly observable damage done to the horse, but from sprains in the attempt to regain a foothold. Injury of

Copland. that kind was far more serious, more insidious, and less easy of cure. He concluded that, in all crowded streets, asphalt as a surface pavement should be given up. He agreed with Mr. Scott, that it might be used with advantage for the paving of narrow courts, alleys, and playgrounds for children; but the safety of grown-up people ought also to be considered, who, in crossing crowded thoroughfares, were constantly run over by horses, which on asphalt roads trotted at a great speed, and were pulled up with difficulty. The durability of all roads depended to a great extent upon the character of the concrete. He found that lias lime, properly used, was as good as cement, but it was necessary that it should be ground to a fine powder, and that it should be fresh and uniformly mixed, care being taken not to use too much water.

. Greig. Mr. H. A. Greig desired to challenge a statement made by the Author to the effect that some Sicilian asphalt had been tried in Paris and condemned, and that therefore very little of it was in use. Mr. Alfred Rumball, M. Inst. C.E., had visited Sicily in August 1877, and reporting on the asphalt deposits, said: "Some quarries have been worked by a French company, but are now abandoned, as all the top seams have been worked out; the quality also is very inferior, containing only a small percentage of bitumen." In the same report there was a strong recommendation that this asphalt should never be touched. The asphalt in Sicily that the United Limmer Company had purchased, on the advice of Mr. Rumball, was of a very different description. Of it he had stated, "The quality will be found very superior, for fineness of colour, closeness of grain," &c. That asphalt had been brought over rather more than two years ago; it was compressed, and Newgate Street was then laid with it, and now showed no "waves" or undulations; it was, he believed, as fine a piece of asphalt as could be seen either in London or in Paris. Other streets in London had also been laid with this Sicilian asphalt for the Commissioners of Sewers for the City.

r. Cowper. Mr. E. A. Cowper observed that no one had touched upon the cheap method of making footpaths in the neighbourhood of London, with tar and gravel, as now practised. A few years ago the material was mixed with stones and gravel, forming a sort of pudding, the whole thickness being put in at once, and as soon as the hot weather came, the tar exuded from the top, making a very bad, soft footpath. Of late years large stones alone had been put at the bottom, which, having received a coating of tar or pitch, just touched each other at points with their tarry surfaces. Above that a thin coating of finer material was placed, with a thin coat

of fine stuff on the top. This made a splendid path; no tar exuded from the top, as any surplus drained down to the bottom, and the path was firm, hard, durable and clean. Mr. Cowper.

Mr. J. Lovegrove desired, having had some experience in the use of asphalt on public footways, to make a few remarks. In the year 1869, when in Paris, he observed the peculiar condition of the roadway opposite the Tuileries; the asphalt appeared to have worked up into leaf-like layers, in a plastic state, and those layers occurred at distances of about 100 feet. He had little doubt that the cause was that the road had been repaired with asphalt too rich in bitumen. In the same year he also observed the] paving of the road along the Rue St. Honoré; the process appeared to be different from that which was now adopted. There was first a layer, 4 inches thick, of hydraulic lime concrete, and then a layer of about 1 inch of mortar trowelled. The concrete was beaten with instruments similar to the tools used by gardeners for beating turf. On the top was a 3-inch layer of powdered asphalt; the channels were pressed into form by a rammer about 9 inches long and 2 inches thick, and were well rammed; then a heated roller was applied over the whole surface. A roller with eight or ten carriage wheels, working upon a common axle, was also passed over it in various ways for a considerable time. Before he left Paris a considerable portion of the asphalt had to be taken up, and he believed the whole was reinstated. He well remembered the care with which the concrete used in Threadneedle Street was mixed, and the quiet, steady way in which the foreigners worked upon the asphalt. It was a unique piece of work, and he would urge upon all asphalt representatives to endeavour to repeat it elsewhere. Great difficulty had been experienced in keeping in order a short piece of asphalt roadway opposite Hackney Town Hall, divided into three slips by tram-lines, the tram-rail and the asphalt being too unlike to be kept together. He had recently tried a rough course of granite pitching at the side of the rails, which seemed to promise well. If well-dressed stones were laid in bond course, he thought they would answer very well. In 1872 a sample of asphalt had been laid along the footpath at Dalston Junction for a length of 550 feet, by the Val de Travers company, and a second length was laid by the Limmer company. The first sample near Dalston Junction, being subjected to the greater wear, was renewed eighteen months ago; the other length was now wearing near the fence line, the concrete being exposed in patches. In 1874, a layer of $\frac{3}{4}$ inch of compressed asphalt was put along the busy part of Kingsland, and a path was also laid in a Mr. Lovegrove

Mr. Lovegrove. quiet street in Stoke Newington. Shortly after cracks appeared at intervals of about every 12 feet, which he attributed to the contraction of the material during cooling. He did not believe that the concrete was affected. He had that day gone over a portion of the work and tested one of the cracks, and found the concrete quite sound. He had placed upon the table rubbings of three worn-out places; they looked more like a representation of the craters of the moon than of a worn-out asphalt path, but it was an interesting mode of showing the condition of the footpath. Since 1876 about 160,000 superficial yards of gritted mastic asphalt had been laid in Hackney;[1] it was $\frac{3}{4}$ inch thick, and rested upon a bed of 3 inches of concrete. The work had been executed partly by the Limmer Company, the French Company, and Leopold Stiebel. Where the paths were narrow and the stream of traffic persistent in one track, the concrete was making its appearance in small patches. Sometimes in wide paths the stream of traffic was persistent next the fence line, and in these cases the path was apt to wear out. He would suggest that it would be advisable in such instances to lay an extra thickness. Of course, the fall would influence the traffic; if too much fall the traffic would be almost sure to keep to the fence line. It had been said that the quality of the Val de Travers asphalt was proved by its wearing to a film, but that was not peculiar to that asphalt, as the Limmer Company's asphalt behaved in precisely the same way. Common asphalt was more easily fractured, and would not wear to a fine film.

Mr. Davis. Mr. ALFRED DAVIS observed that the compressed asphalt blocks used in Paris were stated to have been unsuccessful. In the United States a block was made of refined and tempered Trinidad asphalt and finely-crushed limestone, thoroughly heated and mixed in about equal proportions, and afterwards subjected to a uniform pressure of 1 ton to the square inch, or about 50 tons to the block. The standard size was 12 inches long by 4 inches wide, by 5 inches deep. The blocks had been laid in several of the New England States, and he believed were being extensively used in New York, Philadelphia, and other American cities. He had seen a piece of this roadway in Philadelphia, after six years' wear, and it appeared in first rate condition, although the blocks were inferior to those now produced. In laying the compressed asphalt block road, a concrete foundation at least 4 inches thick was provided, over which a thin coating of gravel was spread; upon this bed the blocks were set close together and heavily rammed.

[1] *Vide* Annual Reports to the Board of Works for the Hackney district.

The great advantage of this roadway was that it afforded a good foot-hold for horses, and at the same time possessed all the other advantages of asphalt roads as constructed in this country. The press employed in the manufacture of these blocks had a steam cylinder of 40 inches in diameter, worked with a pressure of 90 lbs. per square inch. There was an ingenious automatic arrangement for forcing the block out of the mould, and carrying it away to any desired spot for storage. Mr. Davis.

Mr. Frederick Cox, Chairman of the Streets Committee of the City of London, said he had no connection with asphalt companies or wood paving companies; he was not an engineer, and he had no scientific knowledge whatever, but perhaps he might be permitted to make a few remarks as to the use of asphalt, past, present, and future, in the City of London. The administrators of the City Commissioners of Sewers gave encouragement to every projector to send in any kind of asphalt or wood pavement that was likely to be permanently useful. About thirty different kinds had received a fair and proper trial; most of them crumbled into dust or proved to be utterly worthless, but there were a few that had stood a severe test. In his opinion the Val de Travers was the favourite company; but other companies had laid down asphalt with good results. Mr. Haywood, the engineer of the Commissioners, who probably had had more experience in roadways than any other person in the kingdom, reported, five years ago, that, after trying the various kinds submitted, he found that good compressed asphalt was the cheapest, driest, cleanest, and most agreeable for the general purposes of traffic, and Mr. Cox ventured to say that if Mr. Haywood were giving his opinion now, it would be expressed in still stronger language. The Commissioners had carried out large paving works both with asphalt and wood, and probably the main reason that guided them in putting down so much wood was that the asphalt, especially when put down in great lengths, was found to be extremely slippery. In very dry or very wet weather the foot-hold of the horses was good, but when the pavement was muddy it was extremely inconvenient. It had been suggested that all that was necessary was to clean the streets, but what could be done with a place like Cheapside when ten or twelve thousand vehicles passed over it every day? After eight o'clock in the morning it was useless to attempt to do anything of the kind. At six o'clock that very morning Cheapside had been thoroughly cleansed; at nine o'clock it had not dried, and it was in that peculiar state that, although quite clean, it was very slippery. Grit had to be thrown upon it in order to Mr. Cox.

Mr. Cox. enable the horses to stand, and that state of things continued until the afternoon, when the rain came on and converted the grit into mud, which was probably so still, unless the heavy rain that had since fallen had washed it into the gullies. If cleanliness could be accomplished, in his opinion asphalt would be the best roadway for all the main streets; its use had, however, been attended with great difficulties, and the authorities had not yet decided which plan to adopt. To show the difficulties that were experienced, he might mention that three years ago the Commissioners commenced washing the streets, but they were threatened with an injunction from the Court of Chancery for washing concrete down the sewers. The Metropolitan Board of Works, who had the care of the main sewers, said, "It is all very well to wash your grit into our main sewers, but we must be careful what we do, because the Conservancy Board are threatening an injunction against us for raising shoals in the bed of the river." That, however, did not frighten the authorities in the City, who went to an expense of £10,000 in providing large catch-pits to the gullies in the City in order that the deposits might be removed, which was done almost daily. Then arose a question about the water-carts, which caused so much obstruction in the crowded streets that the police interfered. The authorities had endeavoured to deal with that, and they had spent £20,000 during the last two years in erecting hydrants in every street and court in the City, both for the purpose of extinguishing fire and of watering the streets. Those hydrants were just completed, but had not been set to work. With regard to wood pavement, he believed it was one of the dirtiest and greasiest pavements ever put down in the City of London. Dirt was carried from it over 100 or 200 yards of the asphalt, and rendered that which was previously clean excessively dirty. He believed if the Commissioners could succeed in getting clean asphalt, so as to avoid slipperiness, wood pavement would make very little progress in the City of London, except upon gradients that were not suitable for asphalt.

Mr. Delano. Mr. W. H. Delano, in reply, said his experience in reference to scavenging was confined to Paris, where the work was effectually done both in wet and dry weather. Gangers were constantly at work, and they were paid about 3½*d.* an hour. The gully holes placed under the curbs were large and the drains were roomy, so that the slush was easily passed down them. Hydrants had been erected all over the city, and after heavy rains they were used to flush the roadways and carry the mud into the drains. Of course it got into the river and formed banks, but that was the

affair of other authorities. He would suggest that the catch-pits to which Mr. Cox had alluded might be emptied by a pneumatic system of pumping into carts. Formerly mud carts were employed with revolving brushes to take up the slush; but he believed they had been superseded. It was evident that scavenging could not be done in London without considerable expense; but probably London mud, like Paris mud, contained fertilising qualities, so that some set-off might be obtained. With regard to the granite sets in Paris to which Mr. Ellice-Clark had referred, he had given particulars of the cost, and also of the cost and maintenance of the macadam, in the Appendix to his Paper, and an interesting report had been presented upon the subject by M. Vauthier. As to the cracks which had been so frequently mentioned, he believed they resulted in nine cases out of ten from the concrete. If mastic asphalt was placed on wet concrete it would blister and sometimes crack, especially if the bitumen used as a flux to melt it was not well purified. Some engineers used straight joints to prevent cracks. He had also seen hoop iron put in between the concrete at certain distances when it was not too thick. It was always well that the asphalt, liquid and mastic as well as compressed, should be sufficiently thick. Unfortunately Municipal Boards often required things to be done cheaply, and hence the thickness of the asphalt was less than it ought to be. In Paris, where a fifteenth part had to be renewed every year, thickness was not such a desideratum. In the case of gritted mastic, the thinner the mastic the finer the grit should be. Where the mastic was thick, a coarse grit might be used, as shown by the specimen of asphaltic concrete on the table. There were few compressed footpaths in Paris. In 1874 he laid on the Pont Royal about 200 square mètres of this material, under the orders of M. Allard, now Chief Engineer of the City of Paris, and it was now in good order. At one part it was laid $\frac{9}{16}$ inch thick, in other parts $\frac{3}{4}$ inch, and in others 1 inch. It had a better appearance than mastic, but it cost more, because the thickness was greater. The specific gravity of compressed and mastic asphalt was about the same, but the grit put into the mastic made it harder than the compressed material. The statement that asphalt neither contracted nor expanded was certainly an error. Of course the laying down of footpaths with gritted mastic depended a great deal upon the climate. In Marseilles the workmen would put into the cauldrons as much grit as they did asphalt, making a stiff mixture, which required great muscular strength to lay down $\frac{9}{16}$ inch in thickness, but when it was laid it answered very well. No practical worker Mr. Delano.

r. Delano. of asphalt would ever use compressed asphalt as a coating for masonry, because it had not sufficient elasticity. Coatings of masonry were generally put down $\frac{9}{16}$ inch thick, and they required a good deal of bitumen; sometimes the layers were vertical, at other times convex, and frequently had to be inserted in recesses in the masonry prepared for the purpose. Portland slabs had been suggested as a concrete, but he did not think they would answer, because they would require concrete underneath to keep them level. He had been reproached for not having alluded to asphalt as a covering for roofs, but his experience having been limited to France, where such applications were well known, particularly in the south, he supposed that engineers in London who were familiar with such applications would themselves refer to them. The applications of asphalt were almost endless. He had just seen a veteran asphalter in London who had shown him some work that he had done at the Horse Guards stables forty years ago. Up to the 31st of December, 1877, the chief cause of the want of stability of the compressed asphalt roadways in Paris was owing to the hydraulic lime concrete being only 4 inches thick, covered with a lime mortar floating, whereas a layer of 6 to 9 inches of Portland cement without floating was indispensable. Since the 1st of January, 1878, Lobsann asphalt had been used instead of Val de Travers and Seyssel as heretofore, which, according to the report of the Paris engineers, had not sufficient stability. Seyssel mastic was chiefly employed in France for footpaths and coatings for masonry, whereas Val de Travers had been more largely used for compressed asphalt roadways, although by no means exclusively. Wood pavement had not succeeded in Paris, the only important specimen on the patent plank foundation being the Rue St. Georges, which was partially in a bad state, although subject only to light traffic. In several cases wood pavements had been taken up in Paris within the last eight years, and replaced with granite sets and compressed asphalt. Wood was not a material of invariable density like compressed asphalt, the heart being always harder and less absorbent than the outer rings. It had, however, the great advantage of comparative insonority, though vibration was perceptible, and it was excellent for inclines exceeding 1 in 50. He thought that sound oaken sets, with bevelled edges carefully laid on good cement concrete with $\frac{1}{4}$ inch joints filled in with pure asphalt mastic, would render good service for roadways in dry climates, but he doubted if any pure wood pavements would last in Paris or in London much over three years without costly repairs. The smell from rotting wood pave-

ments saturated with the filth of large towns must be deleterious. Mr. Delano. It was well known in Paris that Sicilian asphalt had been taken out of the list of asphalts approved by the city engineers for roadways since 1872. He had been prohibited from employing about 1,500 tons from Ragusa, Sicily, for roads in Paris, and had used a good deal of it as ashlar. This rock was available for flags, staircases and balconies; it was susceptible of delicate carving for architectural ornaments. There were three qualities, one rich in bitumen, the second medium, and the third poor, the latter being a coarse grained yellow stone with the appearance of sandstone. If it would last three years under heavy traffic in London without repairs, such a test would class it as a material for roadways. It was quite possible to make bad work with good materials, though the converse was not true. Still, when good asphalt, properly ground and heated and well laid by careful workmen, did not stand, it was almost always the fault of the concrete. Laying on wet concrete, or using burnt powder was sometimes a cause of failure. Sets of pure Seyssel and Val de Travers powder, compressed in a mould 4 inches square and 2 inches deep, had been successfully used in Paris, but there would be a difficulty in repairs; it was also cheaper to lay hot powder in large towns. Some artificial sets, 8 inches cube, composed, he believed, of gas tar mastic and gravel, had been laid last autumn in the Rue Neuve des Petits-Champs, at the angle of the Rue Vivienne. The piece had been frequently repaired, as the surface wore away and crumbled under the traffic, which was not heavy. He had no confidence in bituminous concrete for roadways, except when used as a foundation for compressed asphalt instead of Portland cement concrete. With reference to the Seyssel and Val de Travers mines, he had hoped that the engineers who had worked them would have been present and given personal explanations. He might mention that the mines were easily worked; there was no choke-damp in them, and little water. The rock was blasted with powder, dynamite not being used because the asphalt was tenacious in its nature. It had been stated that the test of asphalt was its durability. His object in writing the Paper was that any engineer, surveyor, or architect, in specifying asphalt might have some other test. Asphalt might be adulterated; but the tests he had given would enable an architect or engineer to satisfy himself. With reference to the question of nomenclature, "asphalt concrete" had been alluded to in Mr. Deacon's Paper; but he was sure from the context that gas-tar concrete was meant, which was a different thing. Mr.

Mr. Delano.

Cowper also had referred to pitch and tar pavements; but pitch and tar were not asphalt. It was most important not to confound them in specifications, as their respective values and properties were widely different. Considerable areas of compressed asphalt had been laid in Berlin, Vienna, Pesth, Brussels, and New York, and he regretted that no engineer had described the mode of laying.

Correspondence.

Mr. Bixio.

Mr. MAURICE BIXIO, President of the Paris General Cab Company, owning about twelve thousand horses and six thousand vehicles gave the results of his experience as to the most suitable material for roadways for vehicular traffic. The worst pavement was porphyry (grey Belgian granite sets, 4 inches by 6 inches). Falls of horses were much less frequent on asphalt, macadam, or rough pitching (sets of Fontainebleau gritstone 8 inches cube). For the horses, falls on asphalt were less dangerous than on any other material. Beyond all doubt traction was less on asphalt than on any other pavement. His company had made many experiments on this subject, from which he would quote, at random, the following, relating to the French four-wheeled cab, weighing 658 kilogrammes (1,447 lbs.):—

	Kilogrammes.	
Traction on rough pitching	16·37	(36 lbs.)
„ small sets	14·79	(32·5 lbs.)
	Min. Max.	
„ macadam	14·0 to 20·5	(30·8 to 45 lbs.)
„ compressed asphalt (Val de Travers)	12·79	(28 lbs.)

It was probable, though difficult to establish otherwise than by comparison, that the wear and tear of the different parts of a vehicle was less rapid on asphalt than on other pavements. But the comparison did not apply in its entirety to macadam, in which case the tires of the wheel and the horse-shoes were the only parts that wore out more rapidly than on asphalt. The difference of wear was due to the jolting produced by sets, which naturally induced friction between all parts susceptible to that action. He thought that, traction being less, fatigue to the horse would also be less; but that was only an opinion, and not based on actual experiment. Asphalt was excellent also for granaries and for lining wooden mangers. For the paving of stables his company had made few experiments with the material, but as far as they had gone they were well satisfied.

Mr. Chabrier.

Mr. ERNEST CHABRIER wished to deprecate a practice which had been tolerated for some time in the depôts of the city of Paris,

viz., the mixture of several kinds of asphalt, with a view to obtain an average quality which would be supposed capable of meeting general requirements. The principal quality to be sought for in rock asphalt for laying on roads was, the greatest possible homogeneity in the grain of the limestone, and equal regularity in the amount of the bituminous matrix. The greater this uniformity the longer would be the endurance of the asphalt roadway. He would illustrate this by referring to the fact, well known by all engineers concerned with roadmaking, that a mixture of hard with soft metal formed a less enduring surface than one of the softer material alone. The uniform wear of all parts maintained cohesion, which, on the contrary, was rapidly destroyed when a piece of hard stone was, from continual vibration, displaced, without being crushed, thereby leaving a hole. When asphalt rock was not suitable for road surfaces it was either too poor or too rich. In the first case the particles did not cohere; in the second the carriage wheels sank into the material. The practice had been allowed of mixing these two kinds of rock in proportions impossible to be accurately determined, the process being left to the rule of thumb of the workmen. It was only reasonable to suppose that the requisite care was not always bestowed, and in case of bad mixing bad work would result, and a much more rapid deterioration must be expected, on account of the non-homogeneity of the material. It was, therefore, most important that persons proposing to lay down asphalt roadways should, above all things, get the particular rock best suited to the purpose, and further, should seek to obtain it of as even texture as possible. Mr. Chabrier.

Mr. Lavallard. Mr. LAVALLARD, Director of the Stock and Forage Department of the Paris General Omnibus Company, gave some information relative to the traction of heavy vehicles on asphalt carriageways. The standard omnibus of the Paris Company weighed from 1·67 to 1·77 ton empty, and from 3 to 3·6 tons when full. The diameter of the fore-wheels was 4½ feet, of the hind wheels 5 feet, the width of the tires being 2¼ inches. The new three-horse omnibus weighed, when full, from 5 to 5½ tons; the diameter of the fore wheels was 3¾ feet, and of the hind wheels 5 feet, the width of tires being 3¼ to 3½ inches. The company's tramway omnibus[1] weighed, when full, 6 tons, and the diameter of the wheels was 3¼ feet throughout. The result of daily experi-

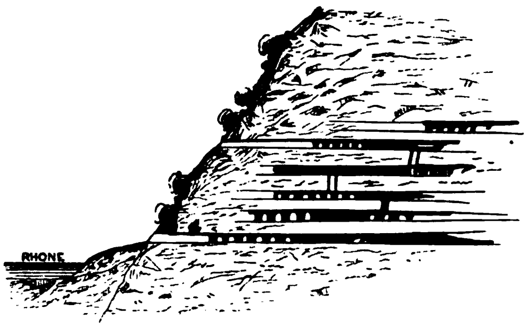
[1] The vehicle used on the tramways of the Paris Omnibus Company is not a car as usually understood, but merely a big omnibus on flanged wheels. The tramway companies use cars of the same character as those in London.

r. Lavallard. ence showed that when the weather was not very warm and the asphalt remained hard, traction on this material was less than on ordinary roadways; but that when the asphalt became softened, by the heat of a fierce sun, traction became considerable and augmented with the rise of the thermometer and the weight of the vehicle. When the asphalt was either dry or wet it afforded a good foothold for the horses. But when the asphalt was beginning to get wet or beginning to dry the horses had much difficulty in keeping up. Under such conditions the asphalt was slippery, and the fall of horses became frequent. This did not, however, affect the traction of the vehicles, which still remained less than on other roadways. The wear and tear of tires, axles, harness, &c., was less on asphalt because shocks were imperceptible. Although, under the conditions named, horses fell more frequently on asphalt than on granite sets, the injuries received were less serious. It, however, resolved itself into a question of shoes, and he thought the adoption of the Charlier horse-shoe had met the difficulty. His company found that asphalt succeeded perfectly as a flooring for granaries and forage stores, but not so well for stables, where it had in most cases to be abandoned, owing to the weight of the horses (from 10 to 12 cwt. each) causing depressions in the material when softened by the warmth of the recumbent animal. The urine collected in these holes, and, moreover, the asphalt was too smooth for the straw, which was always found kicked out behind the stall. Perhaps for horses of a lighter build the inconvenience would not be so great. Latterly they had had reason to believe that the consistence of the subsoil had some influence on the question, because they had stables wherein asphalt floors laid ten or twelve years ago were still in good condition. The cost of maintaining the asphalt laid along their tramways was 1 franc 20 centimes per square metre per annum.

r. Malo. Mr. L. Malo contributed some particulars of the mode of working the asphalt beds in the Seyssel mines, Pyrimont, France. The beds were cut in two by the river Rhone; the workings on the right bank being known as the Pyrimont mine, those on the left as the Volant mine. The layers of asphalt in the two mines were in all respects identical, and it was believed that they originally formed part of the same strata, through which geological action had made the chasm now filled by the Rhone. The beds of asphalt took the form of wide steps, never overlapping but at their extremities. Access to the rock was obtained by galleries (Fig. 4) cut in the hillside; but for the seven workings only two galleries were pierced, one at the highest, and the other at the lowest,

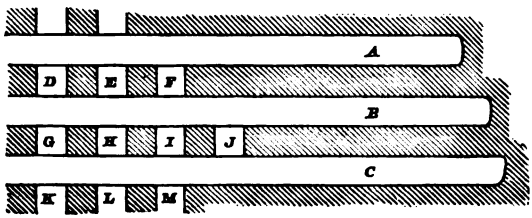
levels; the intermediate stages being reached by inclined planes. The asphalt was brought out at the lowest level. The mines were Mr. Malo.

FIG. 4.



worked on the board and pillar system (Fig. 5), the pillars being about 3·5 mètres (11½ feet) on the side, which width also sufficed for the galleries. These dimensions were arbitrary, for sometimes the roof of the gallery was bad and the pillar got crushed, while in

FIG. 5.

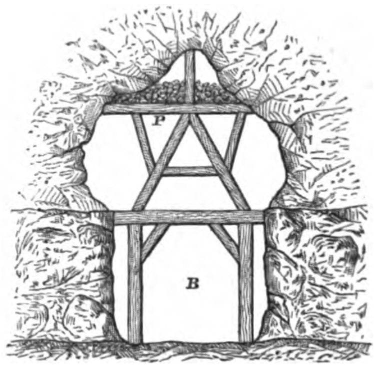


other cases it was good and the pillars had an excess of strength; but the mode of working exacted that the dimensions of the supports should be constant. Nevertheless, when there was reason to fear that the pillars were too weak, the material between several supports was not extracted. When the roof was of good sound rock, timbering was dispensed with; but otherwise it was necessary to support it by oaken baulks, as shown in Fig. 6. It occasionally happened that the roof of a gallery failed, and that the marl fell in such quantities as to form above the asphalt a vast cavity very dangerous to the miners; the least block falling from such a height sufficing to kill a man. In such cases elaborate timbering was resorted to, and a ceiling was laid (P, Fig. 7), on which were placed fascines to deaden the shock of falling rubbish. The rock was got by blasting with powder. Dynamite, and other

Mr. Malo. powerful explosives of a rending nature, had been tried, but had not given good results, on account of the relatively yielding

Fig. 6.

Fig. 7.



nature of asphalt. The beds varied in thickness between 1 mètre 50 centimètres and 4 mètres 50 centimètres (4·5 feet to 14·9 feet), but their extent was not ascertained. The mineral varied, in regard to its amount of bituminous impregnation, from 6½ to 9½ per cent., the poorest rock being as intimately saturated as the richest, although the quantity of bitumen was so much less. It was found that the more homogeneous the structure of an asphalt the more readily was its preparation (*cuisson*) effected; and, further, the more easily it took up the bitumen added to it in the boilers when destined to be made into mastic. Seyssel asphalt was used in two ways; pulverised, heated and rammed, for the well-known compressed asphalt roadways; as mastic, by the addition of a small quantity of free bitumen; in the latter case the material being moulded into cakes and destined to be re-melted for making footways, &c.

Seyssel rock possessed the valuable property of containing the exact proportion necessary for forming a layer of compressed asphalt, at once solid and, to a certain point, unaffected by the heat of the sun. But when not subject to deformation from softening, its manipulation was more delicate than that of other asphalts, and exacted a higher degree of skill in the workman. Mastic made from Seyssel asphalt likewise possessed great advantages, arising from the nature of the rock; but here again the best results were not obtained except by the employment of the purest natural bitumen, if possible similar to that impregnating the rock. Footways in Seyssel mastic, laid forty years

ago, still survived; and some years ago Mr. Malo had taken Mr. Malo. up, in one of the most frequented streets of Lyons—the Place des Celestins—a section of asphalt mastic twenty-five years old, which, though worn to a mere film 5 millimètres (0·19 inch) thick, was still intact, without holes, fissures, or depressions. In conclusion he would remark that the greater number of failures in asphalt works resulted from the contractors not seeing that the material came from well-known mines, or at least from sources vouched for by experts in this industry.

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2 March, 1880.

JAMES BRUNLEES, F.R.S.E., Vice-President, in the Chair.

The following Associate Members have been transferred by the Council to the class of:—

Members.

HAROLD COPPERTHWAITE.
JOSEPH DAWSON.
DRUITT HALPIN.
ARTHUR WILLIAM LAWDER.
CHARLES EDWARD NICHOLAS.
BENJAMIN PRYOR STOCKMAN.
CHARLES EDWIN WARE.
GEORGE WALLER WILLCOCKS.

The following Candidates have been admitted by the Council as

Students.

WILLIAM BASHALL.
CHARLES HENRY BLACKBURN.
THOMAS BOWYER BOWER.
THOMAS SMITH BRIGHT.
JEAN LOUIS NAPOLEON COSTE.
PETER CHALMERS COWAN.
HARLEY HUGH DALRYMPLE-HAY.
ROBERT HENRY BURNSIDE DOWNES.
CONRAD HENRY WALTER GRUNDTVIG.
JAMES HICKMAN.
HERBERT CHRISTIAN HOWES.
MARTIN MILDRED.
ALGERNON SEYMOUR BERNARD OAKLEY.
GEORGE RANKIN.
DAVID WILLIAM ROSS.
ARTHUR JOHN BUCKNALL SMITH.
JOHN TURNER.
HERBERT NICHOLAS WAYLAND.
RICHARD WHATELY.
ALFRED WILLIAMS.

THE following Candidates were balloted for and duly elected as:—

Members.

ATTWILL ELLIS.
HENRY JOHN FRASER.

Associate Members.

FRANCIS ABERCROMBIE, Stud. Inst. C.E.
ALFRED WILLIAM THOMAS BEAN, Stud. Inst. C.E.
GEORGE BERKLEY, Jun.
PERCY WILSON BRITTON, Stud. Inst. C.E.
CHARLES WILLIAM BRYDEN.
GEORGE STEPHENSON CAMPBELL.
ARTHUR BROMLEY HOLMES.
ARTHUR WERNER ITTER, Stud. Inst. C.E.
ARTHUR PINE, Stud. Inst. C.E.
JAMES NAAMAN TAYLOR, Stud. Inst. C.E.
AUGUSTUS BYTHESEA TODD, Stud. Inst. C.E.
CHARLES JOHN HENRY FYLER TOWNSEND, Stud. Inst. C.E.
THOMAS TULLY.
LAWRENCE HERSEE WHITMORE, Stud. Inst. C.E.

Associate.

HENRY EDWARD MCCALLUM, *Lieut. R.E.*

The discussion upon Mr. Delano's Paper "On the use of Asphalt and Mineral Bitumen in Engineering" occupied the evening.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 1592.*)

"Bridge over the Monongahela River at Port Perry, Pa., U.S.A."

By Joseph Miller Wilson, M. Inst. C.E.

The Author of this Paper was directed some time since, in his capacity as Engineer of Bridges and Buildings of the Pennsylvania Railroad Company, to prepare plans for the superstructure of a bridge to cross the Monongahela River at Port Perry, near Pittsburg, Pennsylvania, U.S., for the Pittsburg, Virginia, and Charleston Railway, a branch connecting with the Pennsylvania Railroad, near Brinton's Station. The masonry substructure for the bridge had already been erected, and detail plans of the same were furnished to the Author. Plate 10 shows the general arrangement of the bridge. The bays or openings, commencing at the west end, are as follows:—

First, eight deck spans, varying from 133 feet 4 inches to 138 feet 8 inches in the clear between the copings of masonry; then, one through span over the river channel 256 feet 9 inches in the clear; next, three deck spans, of 70 feet 2 inches, 69 feet 6 inches, and 69 feet 9 inches in the clear respectively, the masonry being in all cases at right angles to the line of the track; then a piece of embankment; and, finally, a deck span over the Pittsburg, Washington, and Baltimore Railroad, of 40 feet 8 inches in the clear, with the masonry 71° askew to the line of the track.

The foundation of the western abutment is 8 feet above low-water mark, and 30 feet below the top of the bank of the river, and is on a cemented gravel. A layer of timber, 12 inches square in section crossed on top with 3-inch planking, was laid on the foundation bed, and on this the masonry was built. The foundations of the river piers are laid on timber throughout. That of Pier 1 is 9 feet below low-water mark, on a cemented gravel. It was found impossible to get below this material with a dredging machine. The timber crib-work, on which the masonry is laid, consists of seven courses of timber of 12 inches each. The con-

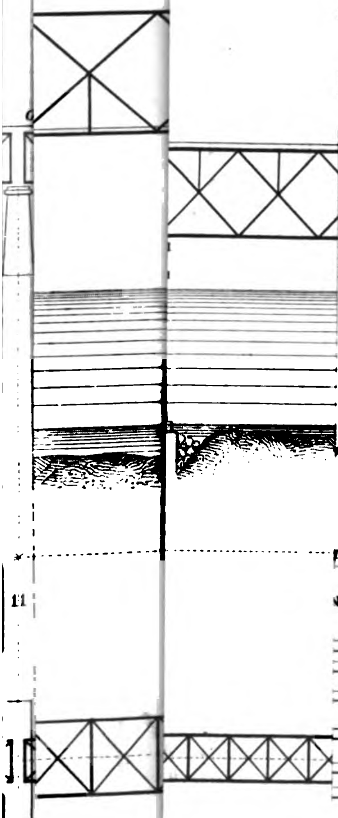
struction of all the cribs is the same throughout, the timber be halved in framing, and the courses spiked together with rag-bo 18 inches long, weighing 3 lbs. each. Fig. 3, Plate 10, shows construction of the crib foundations. On the top of the first cou of timber, half of the space was boarded over, to prevent the sm stones of the filling from falling through, and the spaces w filled with sufficient stone to keep the crib floating in the wa just above the surface, and to enable it to be moved into pl After the crib was placed in the proper position, all the space pockets were filled, and the crib was sunk, leaving the top fi 2½ feet to 3 feet below low water. A rough box was then bu having the bottom formed of 3-inch planks, and the sides of 1-i boards, well braced, the whole being thoroughly caulked. T was sunk on to the top of the crib, and after the water pumped out of it the masonry was commenced, the first cou being 2 feet in thickness. The foundation of Pier 2 is 17 below low-water mark, and there are fifteen courses of timber the crib-work, and 1,000 cubic yards of excavation under wa Pier 3 has its foundation 10 feet below low-water mark, with 8 f thickness of timber in the crib; Pier 4 has the same. Piers 5 and 7 have the foundation 9 feet below low water, and 7 feet timber in the crib. Pier 8 has the foundation 10 feet below l water, with a layer of 8 feet of timber in the crib; and Pier 9, foundation 13 feet below low water, with eleven courses of tim in the crib. The excavation for the piers was done by a dredgi machine, and all the foundations are laid on a very hard cement gravel. The small piers and abutments on the east side of river rest on compact clay, and are about 6 feet to 8 feet from surface of the ground to the bottom. The piers in the river of first-class masonry; the abutments and the land piers on east side are of second-class masonry. First-class masonry understood to be rock range work, in regular courses, bedded a jointed, the backing being in courses, the same as the face-wor and of the same thickness. Second-class masonry is the same, regards the ashlar, as first-class, but the backing is not coursed.

The quantities of material in the substructure are as follow:—

8,082	cubic yards of excavation under water.
2,503	„ „ „ above „
5,249	„ „ first-class masonry.
1,448	„ „ second „ „
7,357	„ „ rip-rap.
36,263	„ feet of timber in the foundations.
9,848	lbs. of iron in the masonry and cribs.
2,919	barrels of hydraulic cement.

OVER

ROAD



...ig. 3.

...N OF CRIBS.

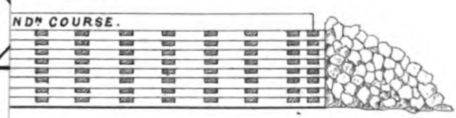


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Fig. 4.

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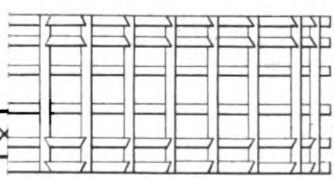

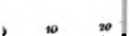

...ings of The

THOˢ KELL & SON, LITH 40, KING ST COVENT GARDEN

HELA
VIRGINIA

PLATE. II.

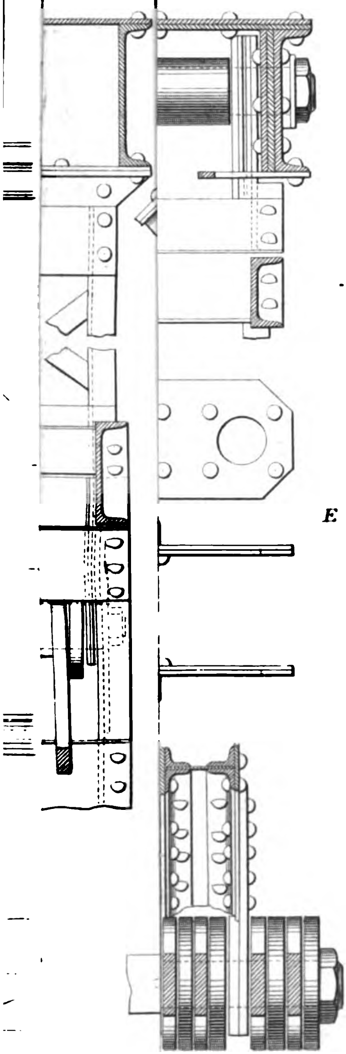

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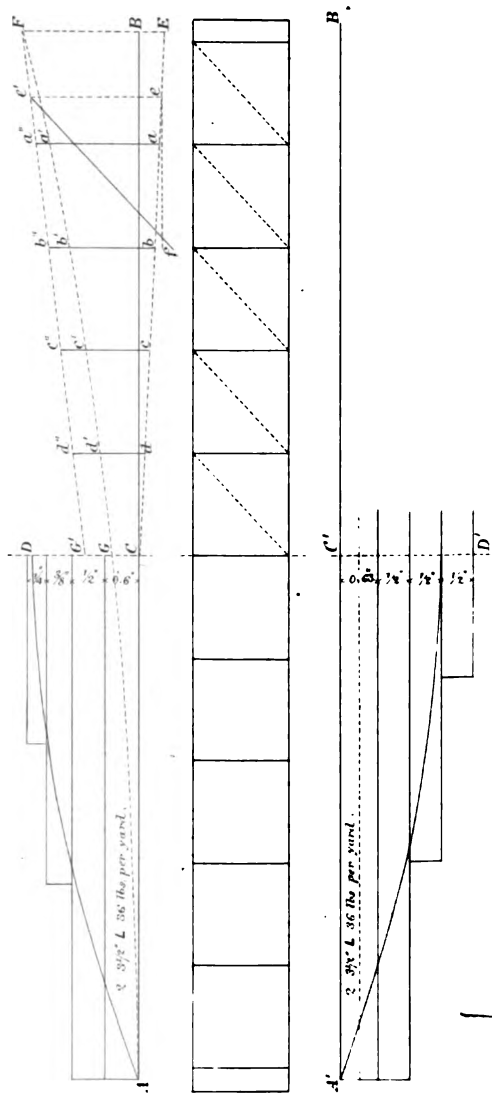
Fig: 11.



Section

GAHELA RIVER.

URGH, VIRGINIA AND CHARLESTON RAILWAY.

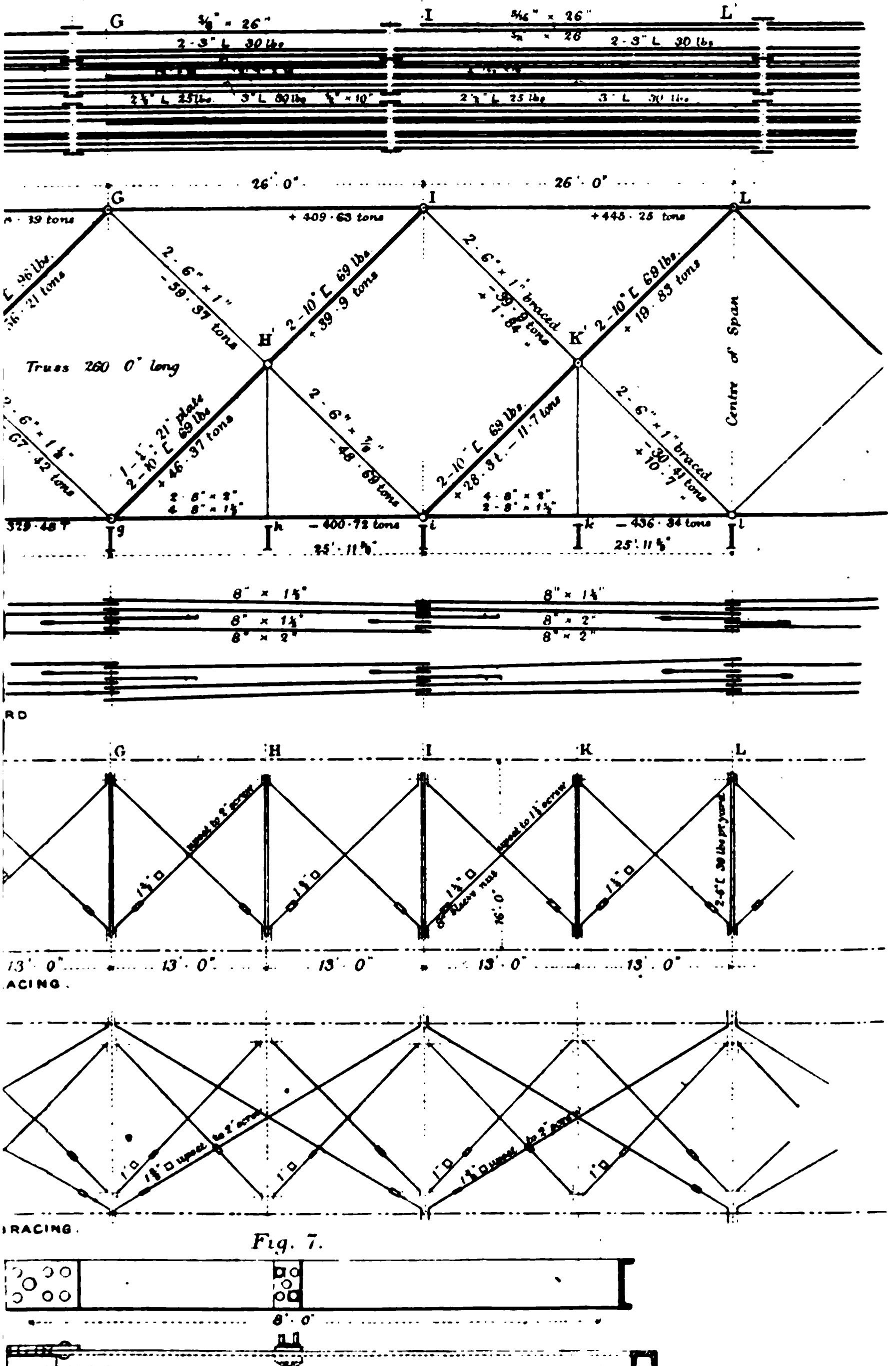


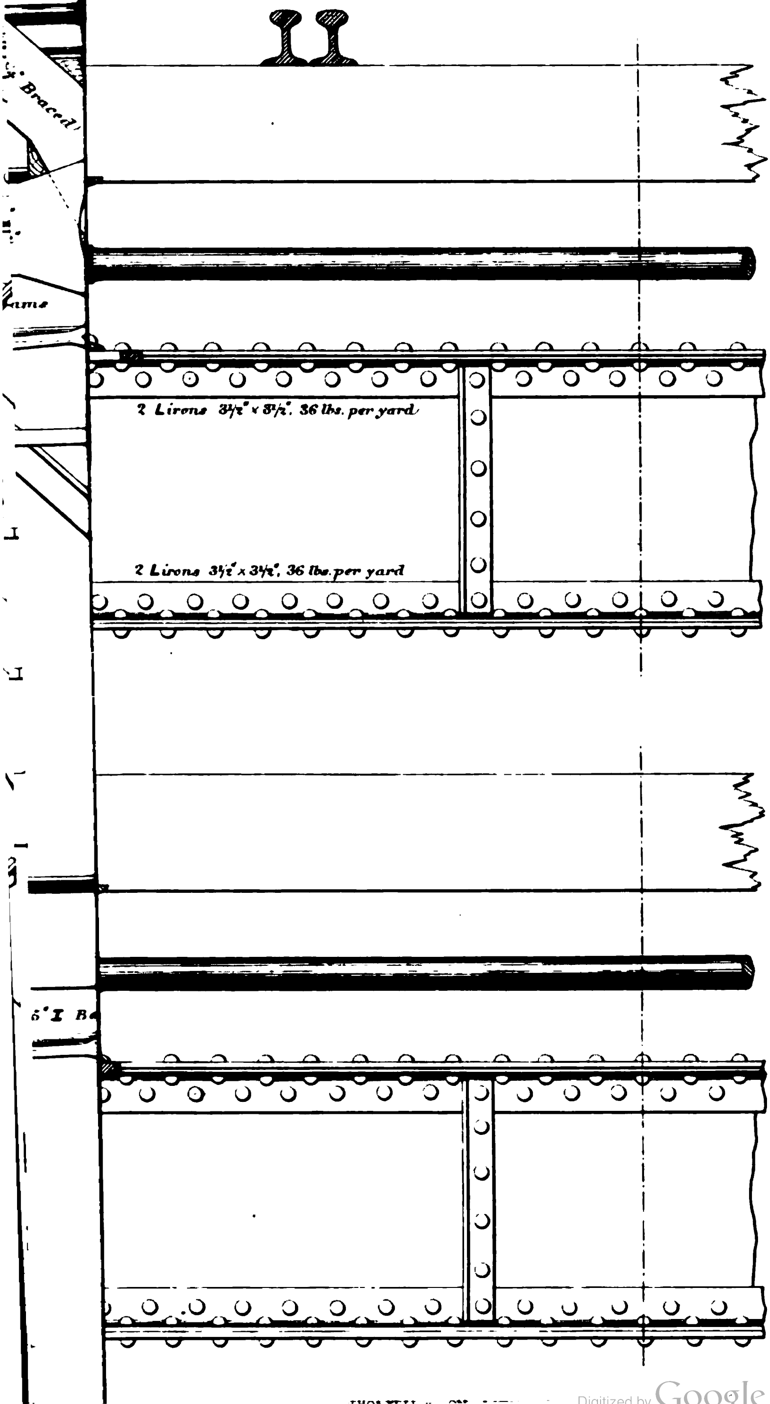
Fig. 7.

8' 0"

END LOWER LATERAL STRUT

NEL SPAN.

THOs KELL & SON LITH 40 KING St COVENT GARDEN


2 L irons 3½" x 3½". 36 lbs. per yard
2 L irons 3½" x 3½". 36 lbs. per yard

In the preparation of the plans for the superstructure, the Author was directed to design the span over the Pittsburg, Washington, and Baltimore Railroad, in iron, for double-track; and all that portion of the structure over the river, east of and including the channel span, in iron, for single track, so constructed that if at any future time it might be found desirable to extend the width of the bridge for double-track, it could be done without rendering useless the present work. He was also instructed to make the eight spans west of the channel span, of wood, for single track, and to bear in mind that the Pennsylvania Railroad Company had purchased, some time since, the false works employed in the erection of the Newport and Cincinnati bridge over the Ohio River at Cincinnati, consisting of several spans of wooden Howe truss bridge; and that it was desirable to use the iron material from these false works as much as possible in the construction of the new bridge. The plans were accordingly prepared under these instructions. Subsequently, in August 1877, after the labour riots in Pittsburg, he was directed to make the eight spans west of the channel span, also of iron, for single track, in order to lessen the risk of the structure being destroyed by fire.

In the construction of its iron bridges, the Pennsylvania Railroad Company has adopted the system of using solid rolled I beam girders for all short spans, up to such lengths as they may be available for the required live loads; then plate girders of the I form, to spans of 50 feet to 60 feet, and in some cases even 70 feet or 80 feet, above which they become too wasteful and expensive in material, and are replaced by open trusses.

Of the various classes of locomotives in use on the Pennsylvania Railroad, that known as the "I," or "Consolidation" engine, is the heaviest engine in use, and produces the most effect on a given length of track. It has eight coupled driving-wheels, and four leading truck wheels, with a total wheel-base of 21 feet 8 inches, and a distance between the centres of the front and rear driving-wheels of 13 feet 8 inches; the total weight of the engine, in working order, is 91,640 lbs., and the weight of the engine on the driving-wheels is 79,400 lbs.

The maximum loads produced on the bridges by the "Consolidation" engine are equivalent to uniform loads per lineal foot for various spans, as follows, it being understood that where the term "tons" is used throughout this Paper, it refers to tons of 2,000 lbs. each.

Equivalent uniform load per lineal foot for various spans, from the "Consolidation" engine for one track:—

Span.	Load per lineal foot.	Span.	Load per lineal foot.	Span.	Load per lineal foot.	Span.	Load per lineal foot.
5 feet.	4·80 tons.	10 feet.	2·80 tons.	15 feet.	2·60 tons.	28 feet.	2·30 tons.
6 "	4·00 "	11 "	2·70 "	16 "	2·60 "	32 "	2·00 "
7 "	3·40 "	12 "	2·70 "	18 "	2·55 "	40 "	1·83 "
8 "	3·00 "	13 "	2·70 "	20 "	2·50 "	48 "	1·70 "
9 "	2·90 "	14 "	2·60 "	22 "	2·40 "	64 "	1·52 "

For any greater span the load is 1·50 ton per lineal foot. The maximum concentrated load for different spans, as applicable to panel points or supports at these intervals, is as follows:—

Span.	Load per lineal foot.	Span.	Load per lineal foot.	Span.	Load per lineal foot.	Span.	Load per lineal foot.
5 feet.	14·00 tons.	8 feet.	20·50 tons.	11 feet.	25·60 tons.	14 feet.	29·50 tons.
6 "	16·00 "	9 "	22·10 "	12 "	27·00 "	15 "	30·00 "
7 "	18·60 "	10 "	23·80 "	13 "	28·30 "	16 "	31·20 "

Of course the various spans of the bridge under consideration have required a variety of treatment.

In considering the plans of superstructure adopted, it is proposed to take up each distinct portion of the work separately.

1. *The eight spans west of the channel span.*—The nature of the case here points to an open truss construction, which has been adopted. In the preparation of designs for bridges, which has been a specialty with the Author for many years, it has been his constant aim, particularly in regard to open trusses, to approach as much as possible to a type which, while economical in material, should be correct in form, both theoretically and practically; allowing of long panels, short intermediate supports, affording a solid permanent construction, not liable to get out of order through derangement; admitting of no uncertainty of strains, through the presence of unnecessary members in the system of the truss; always keeping in perfect adjustment under all conditions of loading. Manifestly, some form of triangular truss is requisite to meet these conditions, and within the last fifteen years the Author has used several types with more or less success.

The last form or type adopted for trusses of the length now under consideration is that shown on Plate 13. It is a double intersection triangular truss, the braces sloping at an angle of 54°, or as nearly that as possible, with intermediate vertical stiffening members from the points of intersection of the braces to the upper chord, the bridge having, in this case, the track on top, or being what in America is termed a "deck bridge." This

type is believed by the Author to be the same as that recently employed for the Tay bridge in Scotland, but with different details.

The spans from one to eight are divided into two sets of different lengths, the first four being alike, and the last four alike. The details of each set are the same, the only difference being in length of span, which was necessitated by the construction of the masonry.

The following are the general dimensions of the eight spans:—

		Feet.	Inches.
Span 1.—Distance from back wall to the centre of the pier		141	0
Spans 2, 3, 4.—Distance from centre to centre of the pier .		140	0
„ 5, 6, 7.— „ „ „ „ „ .		145	0
Span 8.—Distance from the centre of the pier to the back wall of pier		146	0
Number of trusses to each span	2		
Width from centre to centre of the trusses		9	6
Depth of truss from centre to centre of the chord pins . .		17	10
Number of principal panels	8		
„ sub-panels	16		
Length of panels in the upper chord, spans 1, 2, 3, 4 . .		17	2
„ „ „ lower „ „ „ . .		17	$1\frac{13}{16}$
„ „ „ upper „ „ 5, 6, 7, 8 . .		17	10
„ „ „ lower „ „ „ . .		17	$9\frac{13}{16}$
Length of span from centre to centre of the end pins, upper chord, spans 1, 2, 3, 4		137	4
Length of span from centre to centre of the end pins, upper chord, spans 5, 6, 7, 8		142	8
Height from the bridge seat to the base of the rail . . .		20	8

In small deck bridges, the Author's general practice has been to use two beams or girders under each rail of the track; then, for longer spans, up to 30 feet to 50 feet, depending upon circumstances, where "built" girders are employed, to place one girder under each rail; and as the span increases, to adopt only three girders or trusses for two tracks, spacing them so that, when both tracks are loaded, each truss will carry the same weight. The outer trusses carry each two-thirds the load from one track, and the middle truss one-third each of the loads from two tracks. The use of four girders for short spans is dependent upon some details of the floor system, the facilities it gives for renewals, &c.

Reducing the number of trusses from four to three allows of massing the material and a gain in economy, while the equal distribution of load on the three trusses makes them all of the same size, simplifying their construction, and at the same time, lessening the expense of the floor system, placing the trusses closer together. In the case under consideration, the two trusses were arranged so that the addition of a third truss would complete the bridge for

double track, and each truss was therefore computed to carry two-thirds of the load from one track.

The diagrams and details of spans, 5 to 8 inclusive, are shown by Plate 11, Figs. 1 to 10. Taking spans 5 to 8 as illustrating this portion of the bridge, and assuming in accordance with the tables of loads already given by the Author—

Live load = 1·00 ton per lineal foot for one truss.
Dead " = 0·4 " " " "
Panel " for one sub-panel (8 feet 11 inches) = 15 tons,

the computed stresses upon the several members of the truss will be as given by Fig. 2, Plate 11, in tons of 2000 lbs. each, as follows, the + sign signifying compression, and the − sign, tension:—

SPANS 5, 6, 7, 8.

Upper Chord. Tons.	Lower Chord. Tons.
A C = + 43·75	*a c* = − 50
C E = + 118·75	*c e* = − 125
E G = + 168·75	*e g* = − 175
G I = + 193·75	*g i* = − 200

BRACES.

A *b'* = − 61·25	*a b'* = + 70·0
b' c = − 52·9	*b'* C = + 61·6
C *d'* = − 45·7	*c d'* = + 52·9
d' e = − 38·1	*d'* E = + 45·3
E *f'* = − 30·9	*e f'* = + 38·1
f' g = − 24·1, + 4·9	*f'* G = + 34·0
G *h'* = − 20·5, + 9·7	*g h'* = + 28·9, − 2·5
h' i = − 14·2, + 15·6	*h'* I = + 22·0, + 8·0

a A = + 53 tons.
Intermediate vertical stiffening members, each member = + 18 tons.

The nominal stresses from the uniformly variable live and dead loads, as given theoretically, for the braces, have been increased towards the centre of the bridge, where it is found that the effect from the panel load practically becomes greater than that from the uniformly variable load. The intermediate vertical stiffening members have been computed for the panel load and dead load.

The rules which have governed the proportioning of the material to resist the stresses, as shown by the diagram of strains, are:— a limiting stress of five tons (10,000 lbs.) per square inch of effective section for wrought iron under tension; of 4 tons per square inch on full section for compression in the case of short prisms, modified by Gordon's formulæ for section and length of column, and of 4½ tons per square inch for shearing.

The sections and mode of construction of the several members of the truss, as they have been proportioned according to these rules, may be seen by referring to Plate 11, Figs. 6 to 10.

The floor of the bridge consists of white oak floor beams 7 inches wide by 12 inches deep, placed 15 inches apart from centre to centre, therefore having openings between them of 8 inches, and lying crossways on the top chords of the trusses, being notched on to them ½ inch to keep them in place.

On these floor beams the rails of the track are securely spiked, and outside of the rails, longitudinal guard timbers of white oak, 6 inches square in section, are placed, notched 1 inch on to the floor beams, bolted down to them at every fourth beam, and spiked at the intermediate points.

The upper chords, therefore, in addition to the compressive strain to which they are exposed through the system of the truss, have to resist a cross strain in sub-panel lengths from the floor system, and they have been computed for both strains combined. The upper chord, Fig. 1, Plate 11, is formed of 12-inch channels for the sides, with flat plates for the top, properly reinforced by side and top plates where required, and thickening plates at the pin-connections, the whole being joined together by rivets in the usual manner.

The lower flanges of the channels are stiffened across from one to the other by light bracing.

The lower chord members and such braces as are subjected to tension only, are formed of links, that is, flat bars with upset ends or heads, drilled for pin-connections. Those braces subjected to compression are formed of channels and plates, riveted together, except certain ones near the centre of the span, which are built up of angles and plates. Fig. 3, Plate 11, shows the component parts of the lower chord and braces.

The lateral struts are formed of two channels fastened together securely at the ends, and forming a strut bulged in the centre. They are placed at every sub-panel in the upper chord, at every panel in the lower chord, and at the intersection points of the main braces, midway between the upper and lower chords. Horizontal lateral rods are placed between these in the upper and lower chords, as shown by Fig. 4, Plate 11, and diagonal lateral bracing is used in every panel and sub-panel as shown by Fig, 5. Plate 11.

Details of some of the pin-connections, lettered according to the diagram, Fig. 2, Plate 11, are shown by Figs. 6 to 10. Pin-connections are used throughout, and in addition to the shearing

resistance required, they are all given a bearing surface of not more than 4 tons to the square inch, the necessary thickening plates being provided wherever found essential.

2. *The "Channel" span.*—The form of truss adopted for this span is of the same type as that for spans 1 to 8, but as it is a "through" bridge, the track being supported from the lower chord, and running through between the trusses, the intermediate vertical members, instead of being stiffeners, are ties, and extend from the points of intersection of the braces to the lower chord. The floor consists of wrought-iron "built" cross-girders at the panel and sub-panel points, carrying longitudinal I beams, upon which are laid, notched and fastened, white oak cross-sleepers, 8 inches wide by 10 inches deep, placed 16 inches apart from centre to centre, to which the rails of the track are spiked. Guard timbers are laid longitudinally, and are securely bolted to the ties, exterior to the rails, and guard rails of the same weight and section as the main rails of the track are used inside; this is the same over the whole length of the bridge, being the system used on the bridges of the Pennsylvania railroad.

The following are the general dimensions of this space:—

		Feet.	Inches.
Span from centre to centre of the piers		263	6
Number of trusses	2		
Width from centre to centre of the trusses		16	0
Depth of truss from centre to centre of the chord pins		26	0
Number of principal panels	10		
Number of sub-panels	20		
Length of panels in the upper chord		26	0
Length of panels in the lower chord		25	11⅝
Length of span from centre to centre of the end pins, upper chord		260	0
Length of span from centre to centre of the end pins, lower chord		259	8¼

In "through" bridges for double track with three trusses, the centre truss sustains double the load of either outside truss. In the present case, where only one track is to be used, yet facilities provided for the laying of a second track and the necessary widening of bridge for the same whenever required, the most natural method would have been, either to have constructed the span wide enough for a double track, with only two trusses, or else to have made what would be in the future the middle truss, in the case of three trusses being used, double the strength of the other truss, so that the addition of an outside truss would complete the bridge for a double track. The Author was directed, however, to build both

trusses as "outer" trusses, making them each to carry one-half the load from one track. Whenever a second track, therefore, is decided upon, it will be necessary either to replace one of the trusses by a new centre truss of double its strength, moving the old truss out to take the position of an outside truss, or, to build two new single trusses, one of which will lay close up to one of the present trusses, the two combined forming a centre truss.

Plates 12 and 13 show diagrams and details of the channel span. Making the assumptions for

Live load = 0·75 ton per lineal foot for one truss,
Dead " = 0·62 " " "
Panel " for one sub-panel (13 feet) = 14·15 tons,

the computed stresses upon the several members of the truss will be as shown in Fig. 2, Plate 15, for one-half of the bridge, the amounts being in tons as before—

CHANNEL SPAN.

Upper Chord.	Tons.	Lower Chord.	Tons.
A C	= + 89·05	*a c*	= − 80·14
C E	= + 231·53	*c e*	= − 222·62
E G	= + 338·39	*e g*	= − 329·48
G I	= + 409·63	*g i*	= − 400·72
I L	= + 445·25	*i l*	= − 436·34

BRACES.

A B′	= − 125·9	*a* B′	= + 113·31
B′ *c*	= − 113·65	B′C	= + 101·06
C D′	= − 101·06	*c* D′	= + 89·85
D′ *e*	= − 89·51	D′E	= + 78·29
E F′	= − 78·29	*e* F′	= + 67·08
F′ *g*	= − 67·42	F′G	= + 56·21
G H′	= − 59·37	*g* H′	= + 46·37
H′ *i*	= − 48·69	H′I	= + 39·9
I K′	= − 39·9, + 1·84	*i* K′	= + 28·3, − 11·7
K′ *l*	= − 30·41, + 10·7	K′L	= ± 19·83

End vertical member *a* A = + 89·05 tons.
Intermediate vertical tie at the sub-panel, each = − 17·5 tons.

The strictly theoretical stresses have been increased to the amounts as given by the diagram of strains, Fig. 2, Plate 12, in the same way as previously explained for spans 1 to 8; and the longitudinal girders carrying the floor system have been computed for the equivalent load of engine for a span of 13 feet, as would be necessary in a short span bridge. The same rules for limiting stresses per square inch have been followed as explained previously.

The details and diagrams, as given in Plates 12 and 13, suffi-

ciently explain the manner in which the several members of the trusses have been "built up." The upper chord is formed of plates and angles connected by rivets, and it will be noticed that special care has been taken not to mass the material too much one side or the other of the plane of the connecting pins, or the plane in which the stresses act, but to divide it as equally as possible. The lower portion of the chord is open, the flanges being stiffened together by light bracing across, as in spans 1 to 8. It will be observed throughout, in all the spans of this bridge, that particular care has been taken in designing the details, to make all surfaces, both exterior and interior, easily accessible for painting, and to form no closed boxes.

The lower chord consists of bars or links running in full panel lengths. The braces subjected to compression are formed of channels and plates, except certain ones towards the centre of the truss, ordinarily sustaining tension, and formed of links, but braced to resist compression under certain conditions of the variable load.

Lateral struts are used in sub-panel lengths in the upper chord, with lateral ties throughout, and the cross girders of the floor system serve as lower chord laterals, a double system of lateral ties being employed in the latter case, one set being main laterals, and the other set to stiffen the sub-panel cross girder which does not have a rigid longitudinal connection with the lower chord links, being merely supported by the vertical sub-panel ties. Inclined diagonal bracing, with strut for the same, is used at each inclined brace, running down from the top chord to a sufficient height to allow free passage for engines underneath, and diagonal bracing of the same kind is also used at the end vertical posts. Pin-connections are employed throughout. The details of the floor system are shown by Figs. 7 and 8, Plate 13.

One end of each truss is placed on rollers to allow for expansion and contraction, the amount between extremes of temperature being generally about 1 inch per 100 feet of lineal superstructure, and the other end is fixed. The same arrangement is provided throughout all the spans of the bridge, each span being treated separately. The pier-plates, bolster-blocks, &c., are of wrought iron; the rollers and the square blocks which replace the rollers at the fixed ends are chilled castings.

3. *Spans* 10, 11, 12.—The type of truss adopted for the short spans 10, 11, 12 is a single intersection triangular truss, with vertical posts in alternate panels to stiffen the upper chord for cross strain.

The general dimensions are as follows:—

		Feet.	Inches.
Span 10, distance from the back wall to the centre of the pier		76	0
„ 11, distance from centre to centre of the piers		75	0
„ 12, distance from the pier to the back wall of the abutment		76	0
Number of trusses to each span	2		
Width from centre to centre of the trusses		9	6
Depth of truss from centre to centre of the chord piers		9	11½
Number of panels in the upper chord	4		
Length of panel in the upper chord		18	3 3/16
Number of panels in the lower chord	3		
Number of half panels in the lower chord	2		
Length of panel in the lower chord		18	3
Length of span from centre to centre, end piers, lower chord		73	0
Height from bridge seat to the base of rail		12	4½

The trusses are arranged to carry the same load as in spans 1 to 8, each truss being computed to carry two-thirds the load of one track.

Assuming—

Live load = 1·00 ton per lineal foot for one truss,
Dead „ = 0·25 „ „ „
Panel load for sub-panel length (9·125 feet) = 15 tons,

the computed stresses will be for the various members of the truss, as follow:—

Spans 10, 11, 12.

Upper Chord.	Lower Chord.
Tons.	Tons.
$AC = +36{\cdot}6$	$bd = -62{\cdot}7$
$CE = +78{\cdot}4$	$dd = -83{\cdot}6$

Braces.

$Ab = -54{\cdot}3$	$bC = +40{\cdot}3$
$Cd = -30{\cdot}9, +3{\cdot}0$	$dE = +21{\cdot}0, 10{\cdot}6$

Vertical Members $Aa = +55$ tons; $Bb = Dd = +18$ tons.

The same conditions, rules for limiting stresses, &c., have been followed as in previous cases.

The same system has been carried out with the various parts, connections, &c., as in the previous trusses, the same construction of upper chord, the same lower chord, braces, &c. Horizontal lateral bracing is used in the upper and lower chords, and diagonal bracing is employed in every panel. The floor system is the same as that adopted for spans 1 to 8.

4. *The deck span on the Pittsburg, Washington, and Baltimore Railway.*—The span under consideration is one where it was considered advisable to employ for the superstructure four plate-

girders, one under each rail. The dimensions of masonry, &c., determined the following general dimensions:—

		Ft.	Ins.
Angle of skew to the left	71°		
Clear span		40	8
Span from back wall to back wall		47	0
Height of masonry of bridge, &c., at the base of the rail .		5	10
Number of girders	4		
Length of the girders from end to end		46	$1\frac{1}{8}$
Depth of the girders at ends, centre to centre of chord pins .		4	$1\frac{1}{4}$
Distance from centre to centre of adjacent girders under one track		5	9
Distance from centre to centre of the two inner girders . .		6	5

The rails are carried upon white oak floor beams, 8 inches square in section, placed 8 inches apart in the clear, and laid directly upon the iron bridge girders, being notched on them. Heavy wall plates, 15 inches square in section, are placed upon the back walls. White oak guard rails, 6 inches square in section, similar to those used on the other parts of the structure, are placed longitudinally near the outer ends of the floor beams, notched and bolted on; and a walking plank is spiked down in the centre between the tracks.

The assumptions of loading for this span were—

Live load = 0·75 tons per lineal foot for one girder.
Dead " = 0·20 " " " "

The proportions of the girder were determined graphically, as shown by Fig. 11, Plate 11.

Taking the theoretical span at 45 feet = l
Depth of girder 4 " = h
Dead load per lineal foot = w
Live " " = p

$$w + p = 0{\cdot}20 + 0{\cdot}75 = 0{\cdot}95 \text{ tons},$$

and the stress at the centre of the girder on the upper and lower flanges, due to bending movement is—

$$\frac{(w + p)\, l^2}{8\, h} = 60 \text{ tons.}$$

Taking 3 tons per square inch as the limit for compression for the upper flange will give $\frac{60}{3} = 20$ square inches of section required. Assuming the width of the upper flange plates at 12 inches gives $\frac{20}{12} = 1{\cdot}67$ inch as the thickness of plates required in the upper flange at the centre of the girder. In Fig. 11, Plate 11, lay off C D = 1·67 inch on any assumed scale, A B representing the

length of the girder on the same scale as the elevation of the girder below it, and draw the curve A D B according to the rules for drawing a parabola.

Now, taking two 3½ inch angle-irons, each weighing 36 lbs. per yard = 7·2 square inches of section, to connect the upper plates with the web of the girder, and reducing this section to an equivalent width of flange plates, gives 0·6 in. as the equivalent depth. The thickness of the first flange plate, extending the whole length of the girder, has been assumed at ½ inch. These depths are laid down on C D, on the same scale as C D, and additional plates are added, one of ⅜-inch and one of ¼-inch thickness, until the full depth of C D is made up. The parabolic curve A D governs the lengths of the plates.

The lower flange of the girder has been proportioned in the same manner, as shown by the diagram, the limit for tension being taken at 4 tons per square inch of effective section. The effective section required $= \frac{60}{4} = 15$ square inches. Two 3½-inch angles each = 36 lbs. per yard, reduced by rivet-holes, give 5·95 square inches. The rivets used are ⅝-inch, in four lines in the lower flange; hence the effective width of the lower flange is equal to 12 inches less ⅝ by 4 = 9½ inches. Reducing the effective section of the angle-irons to the effective width gives the equivalent depth of the angle-irons = 0·626 inch. The total depth required is $\frac{15}{9 \cdot 5} =$ 1·58 inch, which is made up by angle-irons = 0·626 inch and two plates of ½ inch each, a third plate of ½ inch being added at the centre of the girder to cover joints.

In reference to shearing stress, the dead weight alone gives the shearing stress at end of girder as $\frac{w\,l}{2} = \frac{0 \cdot 2 \text{ ton} \times 45 \text{ feet}}{2} =$ 4·5 tons.

This amount is laid down by scale on B E, Fig. 11, Plate 11, and the line E C drawn.

The variable load gives for shearing at the end of the girder $\frac{p\,l}{2} = \frac{0 \cdot 75 \text{ ton} \times 45}{2} = 17$ tons—which amount is laid off on the same scale on B F.

The parabolic curve A G F, which is the curve of the shearing strains, is then constructed, and the lines *a a′*, *b b′*, *c c′*, &c., are measured on the same scale as used for the forces at B E and B F, and these will give the amount of shearing at the respective vertical stiffeners of the girder. This is under the supposition of

a uniform live load of 0·75 ton per lineal foot for the girder. A heavy engine running over the girder, however, will produce a considerable greater strain on individual members towards the centre of the girder than this shows, decreasing towards the abutments. To meet this, it has been the Author's custom to increase the results by moving the point G up to some point G′, in this special case, making C G′ = 2 C G (a little more, perhaps than is necessary), and drawing the straight line G′ F; the lines $a\,a''$, $b\,b''$, $c\,c''$, $d\,d''$, C G′, giving the stresses at the various upright struts of the girder for which the parts must be proportioned. In general, particularly with small girders, the sizes of iron practically unnecessary are far in excess of the theoretical requirements.

The web of the girder in the present case is made of the same thickness throughout; it is, therefore, only necessary to determine what thickness is required in the end panel of the girder, where the effect of the loading is greatest. The vertical line $e\,e'$ gives the vertical value of the stress acting upon the web of the end panel of the girder; and drawing $e'f$ parallel to the diagonal of the panel, $e\,f$ being a horizontal line, $e'f$ represents the value of the maximum force acting on the web of the girder for a section equal to its thickness into the length of its diagonal.

The stresses on the different parts of the girder subjected to shearing, are,

VERTICALS.

	Tons.
E F =	21·5
$a\,a''$ =	18·75
$b\,b''$ =	16·0
$c\,c''$ =	13·75
$d\,d''$ =	11·2
C G′ =	8·5

Web-plate of the end panel, diagonal stress = 30 tons.

In calculating the number of rivets required for the web-sheets, it will be noted that the end-panel web has a stress of tension upon it, in the direction of its diagonal, of 30 tons, the vertical and horizontal components of which are 20 tons and 22½ tons respectively. The horizontal rivets at the top or bottom of the web take the horizontal component of stress, and the rivets in the vertical struts take the vertical component. Assuming the rivets at ⅝-inch diameter, and considering that they resist double shear, gives a section of 0·6 square inch for each rivet, which, at 4 tons limiting stress, makes a resistance of 24 tons per rivet, requiring, therefore, in the horizontal rows ten rivets for each, and in the vertical rows nine rivets. The rivets have been taken at 4-inch

pitch, making fourteen rivets for the horizontal rows, and twelve rivets for the vertical rows. Thus the whole number of rivets in two sides of the web of end panel is twenty-six, and this reduces the effective width of the web plate for tension by $26 \times \frac{5}{8} = 16 \cdot 25$ inches. The whole width of the plate, measured on the diagonal of the panel, is 72 inches; and taking the thickness of plate at $\frac{3}{16}$ inch, the effective section of plate is $(72 - 16 \cdot 25) \times \frac{3}{16} = 10 \cdot 45$ square inches, which, at 4 tons per square inch gives an effective resistance of 41·8 tons, against 30 tons required.

On account of the deterioration to which these plates are exposed from oxidation, &c., the Author does not consider it prudent to use a thickness of less than $\frac{3}{16}$-inch. Plates of this thickness have been in use on the Pennsylvania railway for more than twenty years without showing any bad results. The question of bearing surface on the rivets, analogous to links on pins, also requires consideration in determining the thickness of web. The "grip" of the angle-irons on the web, as they are held by the rivets, particularly after the bridge has been in use for a time, and rust has cemented the joints together, also enters practically into this question.

The vertical stiffeners of the girder are built up as follows:—

E F	$= 2 - 4'' \times 4''$	36 lbs. per yard	2	plates	$\frac{1}{2}'' \times 4''$
$a\,a''$	$= 2 - 4'' \times 4''$	,, ,,	2	,,	$\frac{1}{2}'' \times 4''$
$b\,b''$	$= 2 - 4'' \times 4''$	,, ,,	2	,,	$\frac{1}{2}'' \times 8''$ (splice of web)
$c\,c''$	$= 2 - 3'' \times 3\frac{1}{2}''$	$26\frac{1}{2}$ lbs. ,,	2	,,	$\frac{1}{2}'' \times 3\frac{1}{2}''$
$d\,d''$	$= 2 - 3'' \times 3\frac{1}{2}''$	,, ,,	2	,,	$\frac{1}{2}'' \times 8''$ (splice of web)
C G′	$= 2 - 3'' \times 3\frac{1}{2}''$	,, ,,	2	,,	$\frac{1}{2}'' \times 3\frac{1}{2}''$

Material in the Structure.

The amounts of material in the entire superstructure are as follows:—

Spans 1 *to* 8 *inclusive.* Deck, single track (load = $\frac{3}{4}$ that for double track)—

1,244,733 lbs. of wrought iron.
10,627 lbs. of cast-iron chilled rollers and blocks for pier plates.
7,620 cubic feet of white oak in the floor system.

Channel Span, No. 9.—Through, single track (load $\frac{3}{4}$ that for double track)—

577,870 lbs. of wrought iron.
11,730 lbs. of cast-iron chilled rollers and blocks for pier plates, also cast-iron struts for track girders.
1,520 cubic feet of white oak in the floor system.

Spans 10, 11, 12. Deck single track (load $\frac{3}{4}$ that for double track)—

128,620 lbs. of wrought iron.
1,380 lbs. of cast-iron chilled rollers and blocks, pier plates.
1,560 cubic feet of white oak in the floor system.

Plate girder over the Pittsburg, Washington, and Baltimore railways. Double track—

42,000 lbs. of wrought iron.
280 lbs. of cast iron.
525 cubic feet of white oak in the floor system.

Totals for all spans—

1,993,223 lbs. of wrought iron.
24,017 lbs. of cast iron.
11,225 cubic feet of white oak.

The work has been manufactured, and is being erected, in accordance with the detailed plans furnished by the Author, by the Keystone Bridge Company of Pittsburg, Pennsylvania, whose contract price for the ironwork and erection amounted to 93,000 dollars. The railroad company furnish the timber and do the painting.

The total cost amounts to—

	$
Iron work and erection	93,000
Timber	4,039
Painting	4,884
Engineering and incidentals	4,266
	106,189

The specifications for the work have required that:—"The wrought iron must be of the best quality, tough and fibrous, free from flaws and injurious cracks along the edges. The iron in the tensile members must be double rolled, after and directly from the puddle bar; no scrap will be allowed, and must be capable of sustaining an ultimate stress of fifty thousand (50,000) pounds per square inch on a full section, with an elastic limit of twenty-five thousand (25,000) pounds per square inch, and a minimum stretch of twenty (20) per cent. under the ultimate stress, the test pieces being two (2) inches between shoulders and turned to a breaking section of five-eighths ($\frac{5}{8}$) of an inch in diameter." "When tested to the breaking, if so required by the Engineer, the rods or links must break through the body and not at the heads or eyes. All workmanship must be first-class. All abutting surfaces must be planed or turned, so as to ensure even bearings, and protected by white lead and tallow before shipment. The plates, angles, &c., forming flanges to be carefully butted, squared and close jointed, so that the whole of the ends of the plates may have a bearing, one against another, and not depend upon the rivets to take the thrust. All vertical stiffeners

in plate girders must have tight bearings against flanges at the top and bottom. All rivet-holes must be carefully spaced and punched, so that pieces may come in close contact, and if the holes do not come exactly opposite, they are to be carefully rimed; and the rivets must be of the very best iron, and must perfectly fill the holes, and have full heads. Rivers to be countersunk in all cases where required." "No error of over one-sixty-fourth ($\frac{1}{64}$) of an inch will be allowed in the lengths of bars between centres of pin-holes, nor shall there be any variation in pins or pin-holes, of over one-hundredth ($\frac{1}{100}$) the diameter of the pin. Said holes to be accurately drilled." "Thickening washers are to be used wherever necessary to make the joints snug and tight." "The cast iron to be true and sound, free from flaws or defects of any kind, and fully up to the thickness and dimensions required by the drawings." "All iron work to receive one coat of red oxide of iron in best linseed oil, before leaving the works." "The timber to be of the best quality, free from sap, wind-shakes, loose knots, any large knots interfering with the strength, or other defects." "The whole of the construction to be first-class work, and in strict accordance with the drawings furnished. In all cases figures are to be taken in preference to any measurements by scale. No alterations to be made unless authorised by the Engineer of the Pennsylvania Railroad Company."

The Author, in conclusion, would like to state further, in relation to the adopted arrangement of the trusses for the channel span, that he would have preferred decidedly to build two trusses only for a double track, completing that span for a double track at the present time. Whenever two tracks are desired, they could then have been laid at a uniform distance apart over the entire structure not requiring "spreading" at the channel span for the centre truss, as will now be necessary, and at the same time saving considerable future cost in the channel span for false works taken in erection, &c., in adapting it to a double track. The Author's opinion on this matter was stated at the time the general outlines of the structure were decided upon, but he was overruled, and directed to design the span as it is being built.

The communication is accompanied by eight sheets of drawings, from which Plates 10, 11, 12 and 13 have been compiled.

(*Paper No. 1622.*)

"The Thames Steam Ferry between Wapping and Rotherhithe."

By Frederic Eliot Duckham, M. Inst. C.E.

In olden times, when the Wapping district was submerged, and the river Thames between Ratcliff and Rotherhithe[1] was broad and shallow, a ford existed there; but upon the Wapping marsh being reclaimed, the river deepened, fording became inconvenient,[2] and the "ancient horse ferry," referred to in the Thames Archway Company's Act[3] as occupying the site of their intended tunnel, and as to which Lord Tavistock and others obtained an Act of Parliament in 1755,[4] is supposed to have been established as a substitute for this more ancient causeway. This ferry was within a few hundred yards of the new ferry about to be described. During the Roman occupation of Britain, a horse ferry existed between Dowgate and Southwark, and a similar ferry near where Lambeth Bridge has within late years been built. The former was on the main line of the Watling Street, and the latter on a loop diverging from the main road near Hampstead, and rejoining it at Newington Butts.[5] The priory of St. Mary Overie (St. Mary of the Ferry) was founded by the daughter and heiress of a Dowgate ferryman. This ferry existed until the Priors built the first London Bridge.[2] The Lambeth and Westminster ferry was used until the opening of Westminster Bridge, in 1750, at which time it was one of the most frequented passages over the Thames.[6] This ferry was from time immemorial the property of the Archbishops of Canterbury, who received £20 per annum rental therefrom, and, with the lessee, obtained compensation when the ferry was superseded by Westminster Bridge.[7] The table of tolls varied,

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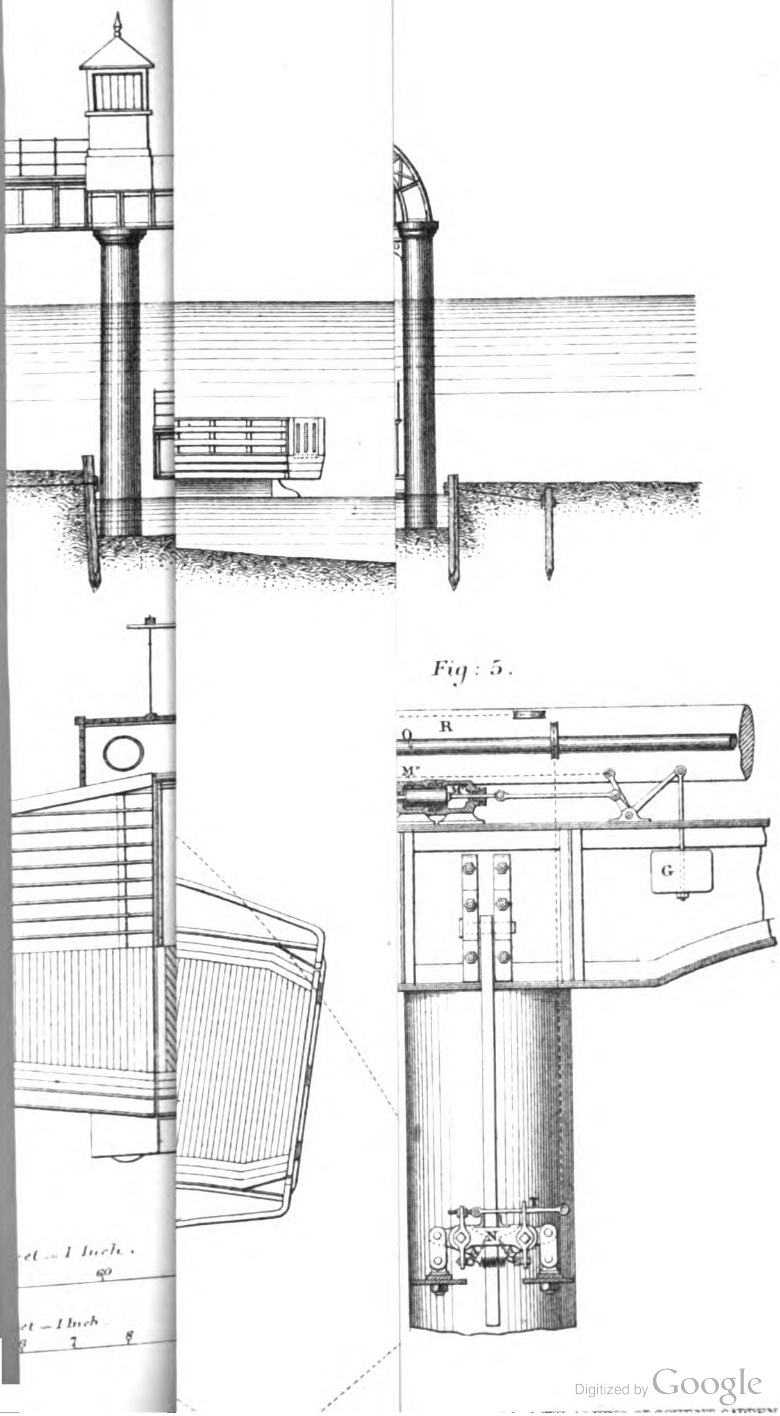
[1] Stow's 'New Survey of London,' &c.
[2] Manning and Bray's 'Survey.'
[3] 45 Geo. III. cap. 117.
[4] 28 Geo. II. cap. 43.
[5] Allen's 'History of Lambeth.'
[6] Allen's 'London.' vol. iv.
[7] Knight's 'London.'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from 2*s.* 6*d.* for a laden wagon or coach and six, to 2*d.* for a man and horse,[1] and much resembles the tariff adopted by the Thames Steam Ferry Company. There was for several centuries a horse ferry between Greenwich and the Isle of Dogs; but this was used chiefly for cattle, and as Pepys records (August 1665) his having to stay on the "Isle of Doggs" two if not three hours to his great discontent waiting for the horse boat to float, it may be concluded that the boat was somewhat irregularly worked.

In 1821 The Poplar and Greenwich Ferry Company was incorporated, to make and maintain roads between the then recently opened City canal and North Greenwich, and ferry-boats to convey cattle and vehicles between North and South Greenwich. The present important parish of Poplar was then but an outlying hamlet. The district was chiefly noted for the trees after which it was named, and for the excellence of its pasturage.[2] The Poplar and Greenwich horse ferry ceased operations in 1840. The flat-bottomed rectangular boats, equal to the transport of a two-horse dray, or eight head of cattle, were propelled by oars, and received or landed their freights at the sloping foreshores of the river. These probably were representatives of the type of ferry-boats formerly used on the Thames, which until a few years since, could be seen near Greenwich pier awaiting the shipbreakers. A small ferry-boat of this class is still employed to a limited extent between North and South Woolwich. Cattle and vehicles have for many years been taken across the river at Gravesend.

The Author knows of no record of the employment of a ferry-boat before the year 1023, B.C.; but, cattle ferries were doubtless in use during previous ages, and they are now to be found in all parts of the world, much to the profit and convenience of most of the great communities which are divided by rivers or waterways. The astonishing exception is London, with nearly half its enormous population, all its docks, most of its heavy trade and commerce, east of the Monument. Until now it has been without any efficient means of conveying vehicles across the Thames below London Bridge.

Several Papers have been read at the Institution on steam ferries: notably that on the Torpoint floating bridge, by Mr. Rendel, in 1838,[3] which bridge was, in 1878, replaced by a similar vessel of iron, instead of wood, but in its dimensions and working

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[1] Nicholson's 'New View of London,' 1808.

[2] Noorthouck's 'London,' 1773.

[3] *Vide* Transactions Inst. C.E., vol. ii., p. 213.

gear almost identical with its predecessor; that on the Kaffre Azzayat ferry, by Mr. Sopwith, in 1857 [1]; and that on the Granton, and the Port-on-Craig ferries, by Mr. Hall, in 1861.[2] In the present communication the Author hopes that the recital of several peculiarities in the arrangements for dealing with the traffic at Wapping and at Rotherhithe will be found of interest.

The Thames Steam Ferry Company was incorporated in 1874, with a nominal capital of £100,000, and limited liability. The site selected for the ferry was directly over the Thames tunnel, 1½ mile east of London Bridge, the intended landing places being near the London docks on the Middlesex shore, and the Commercial docks on the Surrey shore. A special advantage of this site is, that no vessels are allowed to moor within a certain distance of the line of the tunnel, which gives the ferry-boats a clearer course here than is obtainable at any other part of the river.

When the Author was asked to design appliances for working this ferry, the data before him were:

1. A tidal river, 320 yards wide, with a range of 20 feet 6 inches at spring tides.
2. The Tunnel wharf at Wapping, with low-water mark 170 feet from the quay line, and Church Stairs wharf at Rotherhithe, with low-water line 70 feet distant.
3. The instructions were that the ferry should be equal to convey twelve two-horse wagons each way, in addition to foot passengers, every quarter of an hour.
4. A concession from the Thames Conservancy allowing landing stages within certain limits; but insisting that any gangways connecting the stages with the shore should be fixed at a height of 8 feet above Trinity high-water level.

The Author looked to prior examples for aid in solving the problem before him; but in its necessities and surroundings the Thames Steam Ferry scheme differed materially from its predecessors, and required machinery and working arrangements of a special character. Several designs were submitted and considered; and the following was decided upon as best fulfilling the requirements of the undertaking:

Plate 14, Fig. 1 is a side elevation, Fig. 2 a plan, and Fig. 3 the end elevation of one of the landing places, showing a ferry-boat approaching and at the pier, the dolphins to keep the boat in position when receiving or landing its freight, the platform on which the freight

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvii., p. 53.
[2] *Ibid.*, vol. xx., p. 376.

is exchanged, and the hydraulic machinery by which this platform and its load are moved between the road and the deck.

The boats are 82 feet in length, 42 feet in extreme width, 9 feet deep and draw 5 feet of water when laden. They are fitted with disconnected low-pressure paddle-engines of 30 nominal HP. The sponsons are continued in a slightly curved line from outside the paddle-boxes to each end of the boat; the two funnels are diverted from their boilers and brought up through the sponsons. With the exception, therefore, of the engine-room skylights and hatchways, which are placed between the two cart tracks, the boats have a clear rectangular deck the full length of the hull, by 27 feet wide for vehicles; while the foot passengers have ample accommodation outside this line. Platforms are raised above the paddle-boxes to receive the steering wheels. There is a rudder at each end of the boat, but the vessel's course is to a great extent controlled by the engines, which may be worked independently in speed or direction. The bulwarks at the ends are hinged, and can be lowered to form a connecting stage for traffic between the deck and the lift platform. These bulwarks are counterweighted proportionately to the varying strains on the hoisting chains, while moving between the horizontal and the vertical positions. The boats were designed and built of iron by Messrs. Edwards and Symes, of Cubitt Town, and were engined by Messrs. Maudslay, Sons, and Field.

The dolphins are cylinders of cast iron, 5 feet 6 inches in diameter, about 50 feet long, sunk 20 feet into the bed of the river; the upper portion is 2 inches thick; the castings are in lengths of 9 feet, with internal flanges faced and bolted together. In the centre of each dolphin there is a stout balk of timber, imbedded in cement concrete, with which the columns are filled. The dolphins terminate at 4 feet above Trinity high-water mark, where each is surmounted by a dwarf lamp-post, displaying the regulation "two red lights" at night. They are 60 feet apart and 50 feet distant from the lift. With the tide running, say in the direction from top to bottom of Plate 14, the boat's first contact would usually be as shown by the dotted lines. The paddle-wheel near the dolphin is stopped or reversed, the outer engine continues its work, and the vessel is readily brought round into its discharging position, where the current, striking obliquely against the hull, holds it even without the aid of the mooring lines.

The lift platform, or stage, with which the traffic is exchanged by the boats, is 70 feet long by 35 feet wide. It is composed of two single-web girders 5 feet 6 inches deep, connected by cross

girders or joists, mostly of the lattice-girder type. These are 2 feet 9 inches deep, 2 feet 6 inches apart from centre to centre, and carry a flooring of creosoted battens clad with oak. Four cast-iron columns on each side of the lift platform act as guides, and sustain a wrought-iron box girder upon which the hydraulic lifting presses are placed horizontally. The two presses on each of the two girders have their rams connected by the rods O O. Cross girders G′ G″, under the lift platform, carry the brackets and bearings, in which the two transverse shafts S′ S″ rotate when the platform is being raised or lowered. A pitched drum, D, is keyed on both ends of the shafts. The chain from each hydraulic press passes over two sheaves on the ram head, under the corresponding pitched drum on the transverse shaft, and the chain end is brought up again and made fast to the box girder. The platform is thus slung in the bights of the four lifting chains at D′ D″ D‴ and D⁗. The obvious effect of this arrangement is, that should there be a preponderating load at D′, the press R′ would be assisted by R″ through the connecting rods O O; and by R^3 through the shaft S′; R^4 would, moreover, assist R^3 through the rods O′ O″, and R^2 by the shaft S″, &c. Thus each press assists or is assisted by the others, and any movement at one place is correspondingly made at all points; and similarly any strain is immediately transmitted throughout the system. The platforms are moved two units vertically by the rams traversing one unit horizontally. The Wapping platform has a lift of 26 feet, and that at Rotherhithe of 23 feet. One valve in the valve house admits hydraulic pressure to the four lift cylinders, and returns the exhaust water to the reservoir in the engine room. The lift platform is nearly counterpoised by the weights W′ W″, wrought-iron boxes filled with iron kentledge, and connected with the platform by chains passing over sheaves at H H. The weight thrown upon the lift presses is thus reduced to that of the actual traffic, plus such a preponderance of weight in the platform as will enable it to descend without a load when the counterweights are submerged. A wrought-iron double-lattice girder is thrown across the outer end of the lift, arched to clear the traffic, and footed on the outer guide columns to give additional rigidity to the structure. The foreshore under the lift is partially removed, and some sheet piles are driven to form a dock, to which the platform descends at low water.

A jetty to connect the lift with the shore is necessary at Wapping only. It is 100 feet long by 19 feet 6 inches wide for 60 feet, and spreads out like a fan in the remaining 40 feet to the width

of the lift platform. The girders and joists are of wrought iron. The floor resembles that of the lift platform; the shore end is carried by the wharf, the outer end by two of the lift columns, and intermediate there are two 3-feet columns. At Rotherhithe the inner end of the lift platform adjoins the wharf, and the connecting jetty is unnecessary.

The hydraulic power is produced by engines of the type introduced by Sir W. G. Armstrong, V.-P. Inst. C.E. There is one engine at each wharf, having two steam cylinders 12 inches in diameter and a stroke of 18 inches, with direct double-acting force pumps. Steam is generated in vertical boilers each of 15 nominal HP.; of these, two boilers are usually at work and one boiler is in reserve. The accumulator ram has a diameter of 20 inches, a stroke of 20 feet, and is loaded to 800 lbs. pressure per square inch.

The machinery already described has been found to give great security to the lift platform; but, to make the lift quite safe, the special "grabs" shown in Figs. 4 and 5 have been added. A wrought-iron bar 3½ inches square is suspended from the box girders near the four points of support, and is sufficiently strong to bear with safety any strain likely to be brought upon it. The pawls A A have steeled jagged faces eccentric to the pins on which they are keyed; they are connected by a pair of links N N. The pins are prolonged at one side to carry the double levers L L. A strong spiral spring is attached between the lower arms of these levers, and tends to close the pawls upon the vertical bar; but the springs are restrained and the pawls held free by the trigger T. These grabs are connected by massive wrought-iron brackets with the lift platform. A small double hydraulic ram M is mounted by the side of each lifting press; the end M′ has an area of 17 square inches, and is in direct communication with the accumulator; the end M″ has an area of about 16 square inches, and is connected with the adjacent press. The weigh-bar B has three arms, one connected with the ram M, another by a light chain with the trigger T, and the third carries a weight, G, sufficient to pull off the trigger and throw the grabs into operation. The trigger chain passes over a sheave on the ram cross-head, that its connection with the trigger may move at the same rate as the lift platform. Ordinarily the accumulator pressure on the 17 square inches in M′ overcomes the lift cylinder pressure on the 16 square inches in M^2 plus the weight G, and the appliance is in the position shown. Should the accumulator pressure fail or be removed, the weight G overcomes the reduced pressure in the ram M′, pulls the trigger, and the vertical

bar is rigidly held by the grabs. Should the platform counterweight chain break, the whole weight of that portion of the platform and its load would be thrown upon the lifting press; and the excess of pressure in M″ would then overcome M′ with the like result. In the event of a lift-chain failing, the disabled corner of the platform would be freed from its lifting press, but the trigger chain connection would remain intact, and the grabs be thrown into action by the platform on its descending the inch or so of slack allowed on the trigger chain. There is, moreover, a valve in the valve house, by which the attendant may at any time put the grabs into operation, but without giving him the means of interfering with their ordinary automatic action.

The hydraulic machinery was supplied under contract by the East Ferry Road Engineering Works Company of Millwall. The other portions of the works were carried out by Mr. John Gibson.

The method of working the ferry is briefly as follows: the lift platform is ordinarily at a level with the wharf or jetty, and temporarily forms a continuation of the roadway; it is wide enough for four ranks of vehicles; the outgoing traffic usually occupies the two outer ranks, and the pedestrians pass on to the raised pathway on the top of the side girders. As the boat approaches, the platform is lowered to the level of the deck, the boat's prow is dropped, the incoming freight is moved on to the left and the outgoing on to the boat. The boat leaves for the other shore while the platform is raised to the upper level. The load moves off, and the operation is repeated. The time usually occupied in raising the platform from its lowest to its highest level is two minutes; in crossing the river, four minutes. Near high water, however, vehicles have been transferred between Wapping High Street and Rotherhithe church within seven minutes. The ferry is at work from 6 A.M to 8 P.M. The tariff for vehicles with goods varies from 1*s.* to 2*s.* 6*d.*; empties, half price. Cabs, 8*d.*; returning empty, free. Omnibuses, 1*s.* Foot-passengers 1*d.* each. Cattle, &c., are taken at proportionate rates.

Such is The Thames Steam Ferry as constructed and at work. The Author recognises as objectionable features in the scheme: 1st. The large area of the lift platform; 2nd. The use of chains; 3rd. The employment of balance weights. The large lift area was necessary to deal with the estimated amount of traffic. Chains were employed because the Author failed to find any other means than those he has adopted by which a platform of such magnitude could be speedily raised and lowered with ensured horizontality and safety. The balance weights did not exist in the original

design; a second accumulator was therein proposed, with presses at R^2 and R^4 freely connected therewith, while R^1 and R^3 were in communication with the working valve and hydraulic main; but this arrangement was discarded because of its greater cost. The lift chains are $1\frac{1}{4}$ inch, with ordinary pattern short and long links alternately. The counterweight chains are of steel plates, viz., four plates, 3 inches by $\frac{1}{2}$ inch, alternating with sets of three $\frac{1}{2}$ inch and two $\frac{1}{4}$ inch thick; giving a net sectional area of 6 inches in each set.

Ferrying cattle and vehicles was the primary object of The Thames Steam Ferry Company, and obtained for the undertaking the favourable recognition and co-operation of the City authorities. The first lift column was screwed in by Lord Mayor Stone; the first boat was launched by Lord Mayor Cotton; and the ferry was opened for traffic, by Lord Mayor Sir Thomas White, in October 1877. The directors also acquired some valuable land at Wapping in addition to that actually necessary for ferry traffic, and built substantial warehouses thereon, covering nearly $\frac{1}{3}$ acre of ground, and partially fitted them with a complete service of hydraulic cranes, &c.

This communication is accompanied by several diagrams, from which Plate 14 has been compiled.

(*Paper No. 1671.*)

"New Zealand Lighthouses."

By John Blackett, M. Inst. C.E.

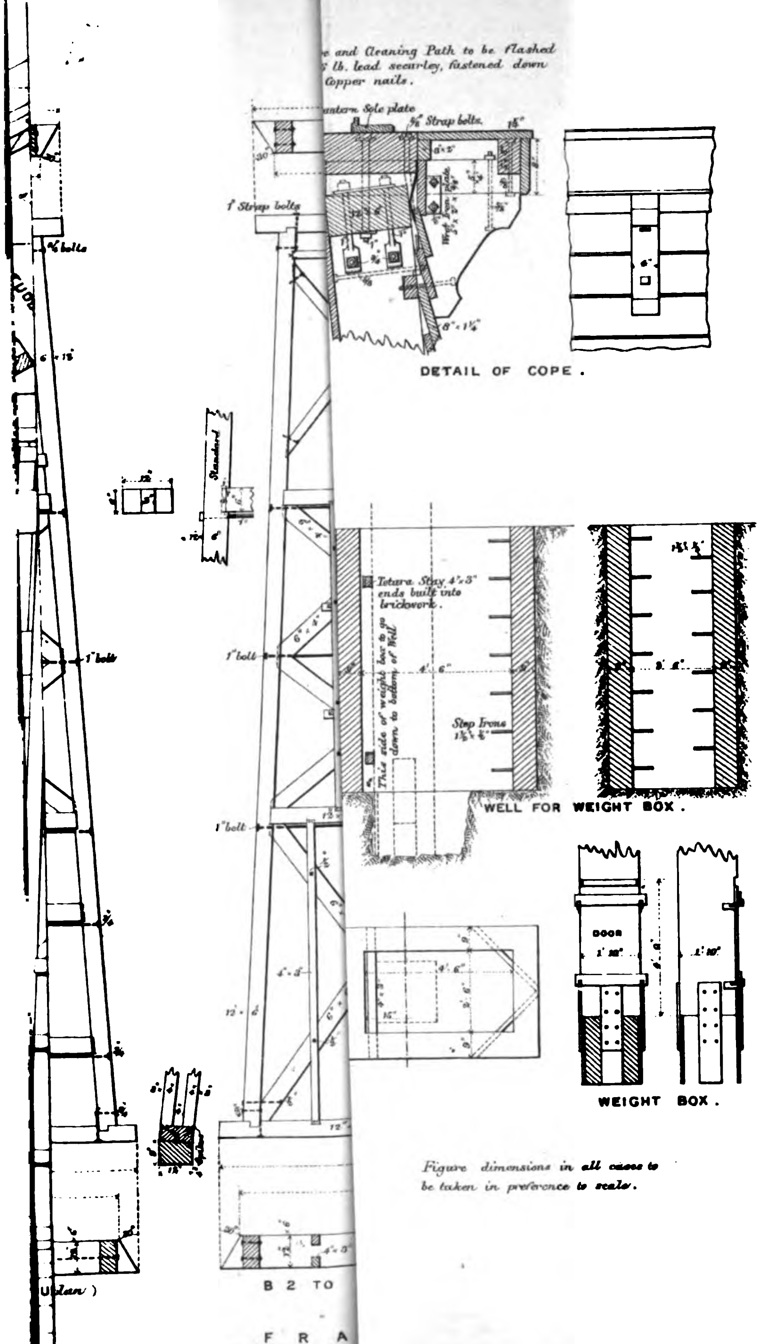
In 1870 the Author was appointed Marine Engineer for the colony of New Zealand, and in that capacity was immediately called upon to arrange for the erection of a number of lighthouses. Two separate trips were undertaken, each being a complete circumnavigation of the Middle and North Islands respectively, for the purpose of determining the sites for the intended lights. During these trips full and accurate information was obtained on which to base a scheme for lighting those parts of the coasts not already provided for, and the work of erection was ordered to be commenced forthwith. The following description will show the progress made in lighthouse construction in New Zealand, and the details may be useful for reference in planning similar structures in other colonies or countries where similar or nearly similar conditions may obtain.

The sites selected presented very various conditions in reference to convenience of access and to the obtaining of materials for construction; several being on the mainland, where the making of roads or tramways was the principal difficulty to be encountered; others on islands, some of which presented fair landing conveniencies, but others being rocky and precipitous demanded special arrangements for landing and conveying the materials and apparatus to the site of the buildings, mostly on the summit.

After due consideration of the subject of materials, it was determined to use timber, not only for the dwellings and stores, but also for the towers, as being cheaper, and more expeditiously erected than brickwork or masonry, and more easily handled at inconvenient or dangerous landing places. At the same time it was considered that well built timber structures would be much less liable to damage by earthquakes, the probable effect of which, on such structures, frequently of a lofty character, and on a comparatively small base, should not be lost sight of, more especially as earthquakes are not of rare occurrence in New Zealand, and are occasionally severe.

To ensure great strength and durability in the towers the

PLATE . 15 .


e and Cleaning Path to be flashed
5 lb. lead securley, fastened down
Copper nails.
antern Sole plate
⅝" Strap bolts.
1" Strap bolts
⅝" bolts
DETAIL OF COPE .
Standard
Totara Stay 4"×3" ends built into brickwork.
This side of weight box to go down to bottom of Well
Step Irons
WELL FOR WEIGHT BOX .
1" bolt
DOOR
WEIGHT BOX .
B 2 TO
F R A
Figure dimensions in all cases to be taken in preference to scale.

Australian timber called iron-bark, which is hard and heavy, has been adopted for all the main framing; and totara, a very durable New Zealand timber, for all the minor parts of the framing and for the outer boarding, &c. The latter timber has also been used for the piles, ground-plates, and weather boarding of the dwelling-houses, stores, &c., which, as a rule, are roofed with stout corrugated galvanised iron plates. One style of construction has been adopted in all the later buildings as ensuring better work and giving more satisfaction than any other method of framing that has been tried; but the whole of the lighthouse towers enumerated in the subsequent list are not thus framed. The same style has been adopted in some of the American lighthouses. On each side of any tower, whether square, hexagonal, or octagonal, is made a separate and complete frame thoroughly braced, and bolted together. The proper number of these frames being placed together, well fitted, blocked, and bolted to each other, constitutes the tower; and this method has been found to produce a building possessing great stiffness and solidity.

The frames thus connected stand on a ground plate prepared for their reception; this, in the case of solid rock, is simply bolted down to it with rag bolts; but in loose rock a deep and wide trench is excavated and filled with concrete to form a solid mass to which the ground plate is secured with bolts. Where ordinary soil or clay exists to a considerable depth, the ground plates rest on a pair of long piles at each angle, either driven or sunk and rammed, and resting on a stout connecting foot-piece.

The framing is purposely made heavy, but to give greater weight and solidity, and to ensure stiffness and immovability in the towers in windy and exposed situations, the spaces between the weather-boarding and inner lining for a height of 8 or 10 feet are filled solid all round with dry clean shingle or broken stone; this has an excellent effect in stiffening the tower.

The towers are ventilated by three or four ventilators in each floor; these open to the air level with the floor, then turn upwards between the weather-boarding and the lining to a height of 4 or 5 feet, where they pass through the inner lining, and are each fitted with a hinged door, by which the supply of air, by one or more according to the force and direction of the wind, is regulated.

The coping-plate is made distinct from the upper top-plate of the main framing, and is kept apart from it by short joists interposed crosswise; this gives a space in which to screw up the nuts of the

holding-down bolts for the lantern sole-plates, and is found to be a convenient arrangement; the lining-boards opposite this space being made fast with screws only, so that they may be easily taken off to give access to these bolts.

The batter of the sides of the towers is 1 horizontal to 9 vertical.

The lantern and lighting apparatus are imported complete and ready for fixing. The lanterns, lamps, and fittings are on the plan of the Northern Board of Lighthouses, United Kingdom; the lights (Dioptric Holophotal) have been supplied by Messrs. Chance Brothers and Co., Birmingham, and latterly by Messrs. Barbiere and Feneste, Paris, the supply of the whole being under the direction and supervision of Messrs. D. and T. Stevenson, of Edinburgh.

Until about 1877 colza oil was used in all the New Zealand lighthouses, but at that time paraffin oil was tried, and being found to answer the purpose well, and being cleaner and cheaper than colza oil, it is now being generally adopted as fast as the necessary alterations to the lamps can be made. One of the lighthouses, viz., that being erected at Hokitika, will be lighted with ordinary coal gas from the town gasworks.

As a rule, the lighthouses in New Zealand are maintained and tended in the ordinary manner with first, second, and third keepers, space being generally found for the erection of proper dwellings for them and their families. In one case only, that of the "Brothers" in Cook Strait, has it been found necessary to establish a "rock station," where three men only are stationed, one man of whom is relieved every month.

The lighthouses built in New Zealand after the year 1870, and those now being erected, up to the present time have cost about £96,000. They are as follows:—

Cape Maria Van Diemen, extreme north .	1st order, revolving 1', visible 24½ miles, with red light over Columbia Reef.
Moko-Huiori, Hauraki Gulf (projected and in hand)	1st order, flashing 10".
Maunkau Harbour, South head . . .	3rd order, fixed, visible 26 miles.
Portland Island, Hawkes Bay . . .	2nd order, revolving 30", visible 24 miles, red light over the Bull Rock.
Napier, Hawkes Bay	4th order, fixed, visible 24 miles.
"Brothers," Cook Strait	2nd order, flashing 10", visible 22 miles, with red light over Cook's Rock.

Cape Foulwind, West coast, Middle Island	2nd order, revolving 30″, visible 19½ miles.
Hokitika, „ „	4th order, fixed (gas).
Akaroa, East coast, „	2nd order, flashing 10″.
Luiraru, „ „	5th order, fixed, visible 14½ miles.
Moeraki, „ „	3rd order, fixed, visible 19½ miles.
Cape Saunders „ „	2nd order, revolving 1′.
Puysegur Point, Preservation Inlet, extreme south-west angle, Middle Island	2nd order, flashing 10″, visible 19$\frac{3}{10}$ miles.
Centre Island, Foreaux Straits . . .	1st order, fixed, visible 22½ miles.

The lighthouses erected before 1870 are as described below, viz.:—

Tiri-Tiri, Hauraki Gulf	1st order, fixed, visible 23½ miles.
Tonui Passage, between Auckland and Thames.	5th order (on iron screw piles).
Cape Farewell Spit, Western head of Blind Bay.	2nd order, revolving 1′, visible 17 miles. Skeleton wood tower, 120 feet.
Nelson, Boulder Bank, Blind Bay . . .	4th order, fixed, visible 12½ miles. Cast iron tower, 60 feet.
Pencarrow, Wellington Heads	2nd order, fixed, visible 30 miles.
Cape Campbell, East coast, Middle Island, south entrance to Cook Strait.	2nd order, revolving, visible 19 miles. Skeleton wood tower.
Godley Head, Port Lyttleton	2nd order, fixed, visible 27 miles.
Taiarou Head, Port Chalmers entrance .	3rd order, fixed, red, visible 20 miles.
Nugget Point, South-east coast, Middle Island.	1st order, fixed, visible 23 miles. Stone tower, 20 feet.
Dog Island, Foveaux Lights, off Bluff Harbour.	1st order, revolving 30″, visible 18 miles. Stone tower, 90 feet.

The two lists together make a total of twenty-four lighthouses, and the coasts of New Zealand, even at this early stage of its history, are well and efficiently lighted.

The communication is accompanied by eight sheets of engravings, from which Plate 15 has been prepared.

(*Paper No. 1680.*)

"The Theory of Modern American Suspension Bridges."[1]

By S. C. Professor Celeste Clericetti, of Milan.

1. It is well known that the engineers of the United States have found a practical solution of the problem of long-span bridges. It is also known that the solution consists of an improvement of the simple suspension system which prevailed in the first half of the present century, but which has lost credit in consequence of its insufficient rigidity.

The railway bridge constructed on the new principle in 1855 over the Niagara by Mr. Roebling, to whom the innovation is principally due, which measures 250 mètres between the towers, and over which locomotives have been running for twenty-five years, is a sufficient proof of the stability of the system, even without mentioning the other five or six bridges, including the last and largest one over the East river, between New York and Brooklyn, having a span of nearly 500 mètres between the supporting points.

The new system, besides its principal element, composed of steel or iron wire cables, includes—

1st. A certain number of straight rigid girders, of the ordinary construction, connected with the cables by a series of vertical rods.

2nd. A series of inclined ropes, radiating from the saddles and supporting the girder at equidistant points, leaving unsupported only about the middle third of the same.

Another source of rigidity in the system arises from the cables, which, instead of being disposed in a vertical plane, are inclined inwards; and also from a series of horizontal ties, which increase the lateral stiffness and diminish the oscillations from high winds.

Neglecting the inclination of the cables and the horizontal ties,

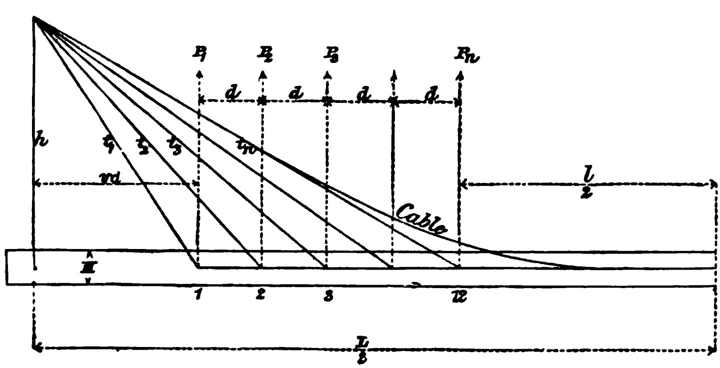
[1] An abridgment by the Author of two communications, "Teoria delle Travature reticolari combinate ad un sistema articulato nei moderni ponti sospesi Americani," read at Meetings of the Royal Institute of Lombardy, on the 12th of April 1877, and the 27th of June 1878, and printed in vol. xiv. of the 'Memoirs' of that body; and of a note "Ponti sospesi rigidi," read before the same body on the 3rd of April 1879, and printed in series ii., vol. xii., of the 'Rendiconti.'

three different elementary structures compose the system just described. First a flexible structure, which is formed by the cable; secondly, an articulated system constituted by the sloping ropes, joined at their lower end by a horizontal tie; and thirdly, an elastic system, the girder.

In the American bridges under consideration it does not appear that the extremities of the sloping ropes are connected by a horizontal tie; they are generally fastened either to the top or to the lower boom of the girder. But it seems to the Author that the completion of the articulated system by a horizontal tie situated along the neutral axis of the girder, where it would only be subject to longitudinal tension, would be preferable to the American custom, which has the disadvantage of increasing the strains, either of tension or of compression along one of the flanges, producing a corresponding displacement of the neutral axis of the girder.

2. In order to ascertain the conditions of equilibrium of the compound system as defined, the Author begins his research by taking into consideration the double structure constituted by a horizontal elastic girder, supported at both ends by the abutments, and at equidistant intervals by inclined ropes, radiating from two points situated on a level on the verticals above the supported ends. The sloping ropes leave part of the girder unsupported towards the middle, which part, in the bridges of this system already erected, varies from one-third to two-fifths of the whole span.

The combined structure is supposed at first to carry a uniform load, distributed over the whole length of the girder, the moment of inertia of which is taken to be constant between two joints, but to vary from one joint to the other.



By the ordinary process of analysis of elastic structures, three consecutive series of equations are deduced. The first series gives the bending moments M_k at any point between two consecutive joints; the second gives the corresponding inclination of the girder, and finally the equations of the third series give the vertical flexure.

By combining the equations of the first series with those of the third, a new series is obtained, which show the following property: the bending moments in any three consecutive joints are connected by the well known theorem of Clapeyron of the three moments. Calling

M_{k-2}, M_{k-1}, M_k the bending moments of the girder in three consecutive joints;

I_{k-2}, I_{k-1}, I_k the moments of inertia of the girder in the same points;

s_{k-2}, s_{k-1}, s_k their vertical displacement from the original horizontal line, passing through the supports;

d = the constant distance of two joints, excluding the middle portion whose length is l;

q = the uniform load on the girder per mètre; and finally

E^1 = the coefficient of elasticity of the material of the same:

then the general expression arrived at, is

$$\frac{1}{d}\left\{M_{k-2} + 4\,M_{k-1} + M_k\right\} = \frac{6\,E^1}{d^3}\left\{I_k\,s_k - 2\,I_{k-1}\,s_{k-1} + I_{k-2}\,s_{k-2}\right\} - q\frac{d}{2} \quad (1)$$

3. The principal condition which arises from the combination of the two structures analysed is evidently this: the vertical displacement of the end of any radiating rope, produced by its elastic elongation, must be equal to the vertical flexure of the girder in the same joint.

Taking into consideration the articulated system, the vertical component of the elastic elongation of the k^{th} sloping rope is easily demonstrated to be, with sufficient approximation,

$$s_k = \frac{R}{E\,h}\,t_k^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2), \text{ being}$$

R = the maximum stress per square unity of rope section;

E = the coefficient of elasticity of the material of the same;

t_k = the normal length of the rope under consideration.

By introducing the above value in equation (1), and by putting

$$I_k = M_k\,\frac{H}{2\,R^1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

H = the constant depth of the girder;
R^1 = the maximum stress per square unit of section of the girder. By putting

$$\frac{R}{E} \cdot \frac{E^1}{R^1} = c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and calling h the height of the points of suspension, above the neutral axis of the girder, equation (1) becomes—

$$M_{k-2}\{3\,c\,H\,t_{k-2}^2 - d^2 h\} - 2\,M_{k-1}\{3\,c\,H\,t_{k-1}^2 + 2\,d^2 h\} + M_k \{3\,c\,H\,t_k^2 - d^2 h\} = q\,\frac{d^4 h}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

This equation contains as unknown quantities only M_{k-2}, M_{k-1}, M_k; therefore by making successively $k = 1, 2, 3 \ldots n$, there will be deduced $(n-1)$ equations with $(n-1)$ unknown quantities, the moment M_n at the last joint near the middle being determined by the Author by a different process.

Putting—

$$3\,c\,H\,t_{k-1}^2 - d^2 h = a_{k-1} \qquad 3\,c\,H\,t_{k-1}^2 + 2\,d^2 h = b_{k-1}\,. \quad (6)$$

$q\,\dfrac{d^4 h}{2} = C$, equation (5) becomes—

$$M_{k-2}\,a_{k-1} - 2\,M_{k-1}\,b_{k-1} + M_k\,a_k = C \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The series of $(n-1)$ equations deduced from this are then solved, by the method of indeterminate coefficients, by introducing two series α and γ, of which the general expression is—

$$\alpha_k = 2\,\alpha_{k-1}\frac{b_{n-k}}{a_{n-k}} - \alpha_{k-2} \qquad \gamma_k = 2\,\gamma_{k-1}\frac{b_k}{a_k} - \gamma_{k-2} \quad . \quad . \quad . \quad . \quad (8)$$

being $\alpha_o = \gamma_o = 1$.

The value of M_{k-1} is then obtained, being

$$M_{k-1} = -\frac{1}{a_{k-1}\,\alpha_{n-1}}\left\{C\left[\alpha_{n-k}\sum_{o}^{k-2}\gamma_s + \gamma_{k-2}\sum_{k+1}^{n}\alpha_{n-s}\right] + M_n\,a_n\,\gamma_{k-2}\right\} \quad (9)$$

The value of M_n deduced separately is

$$M_n = -\,q\,\frac{d\,h}{4}\;\frac{\dfrac{2\,d^3}{\gamma_{n-1}}\displaystyle\sum_{o}^{n-2}\gamma_s + d^3 + l^3}{a_n\left(1 - \dfrac{\gamma_{n-2}}{\gamma_{n-1}}\right) + 3\,h\,d\,(d+l)} \quad . \quad . \quad . \quad (9^1)$$

Introducing this value of M_n in equation (9) and making $k = 1, 2, 3 \ldots (n-2), (n-1)$ all the required moments will be obtained.

These moments of flexure are all negative; it follows that, as on the contrary, the moment in the middle of the girder is positive, there are two points of contrary flexure in its curvature. These points are situated in the portion l of the girder, unsupported by the sloping ropes.

The vertical component P of the tension in any inclined rope is a linear function of the moments of flexure in three successive joints, the middle of which is the end of the rope; the general expression is—

$$P_{k-1} = q\,d + \frac{1}{d}\left\{M_k - 2\,M_{k-1} + M_{k-2}\right\} \quad . \quad . \quad . \quad . \quad (10)$$

$$P_n = \frac{q}{2}\left[L - (2\,n - 1)\,d\right] + \frac{1}{d}\left(M_{n-1} - M_n\right) \quad . \quad . \quad (11)$$

L being the total length of the girder.

But the portion of P_{k-1} and P_n which depends upon the moments, or the second term of each expression, being always comparatively small, either plus or minus, a sufficient approximation for practical use is attained by assuming

$$P_{k-1} = q\,d = \text{constant.} \qquad P_n = \frac{q}{2}\left\{L - (2\,n - 1)\,d\right\} \quad (12)$$

That is to say: the vertical component of the tension on any inclined rope, can be assumed equal to the weights applied to the girder, from the middle of the left, to the middle of the right bay.

When applying these formulæ and the preceding, (10) and (11), it must be remembered that k varies from 1 to n.

The knowledge of the vertical component allows the horizontal component or thrust to be easily deduced, and from any of them the resultant or the longitudinal tension on any inclined rope may be found.

4. In the numerical applications of the summarily recapitulated theory the value of c (4) is assumed by the Author to be $\frac{5}{4}$ when both ropes and girders are of iron, on the consideration that for simple tensile stress, as that to which the ropes are exclusively subject, the maximum stress R can be taken at $\frac{5}{4}$ of the corresponding limit R^1 of the girder. And even should the girder be of wood and the ropes of wire the fraction $\frac{R}{E} \cdot \frac{E^1}{R^1}$ can still be assumed $= \frac{5}{4}$, because the value of E^1 for wood is about 100·000 kilogrammes per square centimètre, while E for iron is 1,800·000 kilogrammes, so that $\frac{E^1}{E} = \frac{1}{18}$. Then, assuming as mean value

$R^1 = 37$ kilogrammes, and $R = 1{,}000$ kilogrammes per square centimètre, it follows again that $C = \frac{1}{18} \cdot \frac{1000}{37} = \frac{3}{2}$ nearly.

The vertical deflection in the middle of the girder is given by the formula

$$s_m = -\frac{5}{384} 9 \cdot \frac{L^4}{E^1 I_m} + \frac{1}{E^1 I_m} \left\{ \frac{d\,L^2}{8} \sum_1^n P x - \frac{1}{6} \sum_1^n P x^3 \right\} \quad (13)$$

in which I_m is the moment of inertia of the girder in the middle, and

$$\sum_1^n P x = P_1 + 2\ P_2 + 3\ P_3 + \ldots\ldots + n\ P_n$$

$$\sum_1^n P x^3 = P_1 + 2^3 P_2 + 3^3 P_3 + \ldots\ldots + n^3 P_n.$$

The Author has applied the preceding theory to some American bridges, amongst them to the Niagara bridge of 1855. As regards the same, Mr. Malézieux[1] states that the deflection of this bridge, when loaded through all its length by a heavy railway train, does not exceed 25 centimètres. The above formula gives

$$s_m = -479{,}749 \frac{R^1}{E^1}.$$

The girder being constructed of wood, supposing the maximum stress in the upper and lower flanges to be $R^1 = 50$ kilogrammes per square centimètre and $E = 100 \cdot 000$, as before stated, then

$$s_m = -0 \cdot 239 \text{ mètre, or 24 centimètres.}$$

In order to explain how this result has been obtained, it is necessary to state that for want of knowledge of the real dimensions of the flanges, and hence of the value of I_m, the Author has introduced in (13) for I_m its value as a function of R^1 and M_m; hence the expression appears as a function of $\frac{R^1}{E^1}$.

The Author has also deduced some approximate values, which are necessary for the further prosecution of the theory, and which are useful for practical applications. The approximate value of the moment of flexure in the middle of the girder is

$$M_m = +q \frac{l^2}{12} \quad \ldots\ldots\ldots\ldots \quad (14)$$

l being, as already mentioned, the length of the middle portion of

[1] *Vide* "Travaux publics des Etats-Unis d'Amerique."

the girder, unsupported by the inclined ropes. The approximation given by this formula, compared with the exact one, which is

$$M_m = q\frac{L^2}{8} - d\sum_1^n P x \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

can be judged by the following results:

		Exact (15).	Formula (14).
1. Niagara bridge of 1855 .	$\frac{M_m}{q}$ =	828,622	833,000
2. East River bridge . .	„ =	1,907,571	2,338,500
3. Bridge of 150 mètres span	„ =	194,000	208.300
4. „ 110 „	„ =	128,348	133,330

The approximate value of the moment at the end of the middle part of the girder is:

$$M_n = -\tfrac{1}{2} M_m = -q\frac{l^2}{24} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

The approximate value of the deflection in the middle is:

$$s_m = -\frac{1}{64} q \frac{l^4}{E^1 I_m} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

which, for the Niagara bridge gives, by the same process as before stated, $s_m = -538,829 \frac{R^1}{E^1}$, and for $\frac{R^1}{E^1} = \frac{50}{100\cdot000}$ $s_m = -0\cdot269$, instead of $0\cdot24$ mètre.

Remembering that the moment of inertia has been assumed variable from one joint to another, this result can be usefully compared with the corresponding value of vertical deflection in a girder of the same material and length, equally loaded, under the assumption that the moment of inertia is variable. Assuming I to be subject to the conditions that the minimum stress R^1 per square unit of cross section of flanges is constant, the Author shows that the deflection in the middle would be proportional to $\frac{6}{384}$ instead of $\frac{5}{384}$, which is the value corresponding to a constant moment of inertia. That is—

$$I_m = -\frac{1}{64} q \frac{L^4}{E_m I_m},$$

which, compared with the last one, shows that the deflection in the two cases would be as the rate $\left(\frac{l}{L}\right)^4$, so that the influence of the sloping ropes is clearly manifest.

Another result pointed out by the theory, and useful for practical applications, is that the distance of the first joint of the radiating ropes should be greater than the succeeding ones, in order to prevent the reaction on the abutment becoming negative; or, which is the consequence, to prevent the sloping ropes carrying all the weight of the girder, a condition which is realised in all the bridges of the system erected in America, in every one of them the first bay being longer than the others.

5. In the second part of the work, the principal object of which is the determination of the influence of moving loads, the point of departure is the general expression—

$$\begin{aligned} M_{k-1}\, l_{k+1}\, [a_{k-1} + h\,(l^2_{k-1} - l^2_k)] - M_k\,(l_{k-1} + l_k)\, b_k + \\ M_{k+1}\, a_k\, b_k = l_k\, l_{k+1}\, h\,(C''_k\, l_k + C'_{k+1}\, l_{k+1}) \quad . \quad . \quad . \quad (18) \end{aligned}$$

in which the distances of the joints are supposed to be variable, being $l_1 \; l_2 \, . \, . \, . \, l_k \, . \, . \, . \, . \, l_n$, and the distribution of load also variable. In the same formula are

$$C^1_k = 2\, M^1_k + M^1_{k+1} \qquad C''_k = 2\, M^1_{k+1} + M^1_k,$$

M^1_k and M^1_{k+1} being the moments of flexure in the joints k and $(k+1)$ separated by the length l_k, if this portion l_k of the girder is fixed horizontally at both ends. The symbols thus adopted suppose the load to be distributed either on a portion or on the whole length of a bay, the case being excepted in which the load is reduced to a single weight applied at a joint. Calling z the length of the part of bay l_k loaded by p per mètre on the left side, so that the remaining portion $(l_k - z)$ is unloaded, the values of C′ and C″ are

$$C' = -\frac{p\, z^2}{4\, l_k^2}\,(2\, l_k - z)^2,$$

$$C'' = -\frac{p\, z^2}{4\, l_k^2}(2\, l_k^2 - z^2)$$

If, on the contrary, the load is applied to the right side, over the length $(l_k - z)$, then C″ must be changed into C′ and *vice versâ*, and z in $(l_k - z)$ in the given values. If the load covers all the bay, then $z = l_k$, therefore

$$C' = C'' = -\,p\,\frac{l_k^2}{4}.$$

The general values of the series a and b are:

$$a_k = 3\, c\, H\, t^2_k - l^2_k\, h \qquad b_k = 3\, c\, H\, t^2_k + 2\, l_k\, l_{k+1}\, h \quad . \quad (19)$$

Equation (18) for $k = 1, 2 \ldots n \ (n+1) \ldots (2n-1), 2n$, gives $2n$ equations containing as unknown quantities the $2n$ moments at the joints. But, as they also contain in each value of a and b the quantity (4)—

$$c = \frac{E^1}{R^1} \cdot \frac{R}{E} = \mu \cdot \frac{R}{R^1}$$

representing by μ a constant, the question would appear insoluble, if the rate $\frac{R}{R^1}$ varied from one joint to another, or in the same joint by changing the distribution of the load. However, calculation leads to the result, that P_k acquires its maximum positive value by the same distribution of load for which M_k is the maximum negative, a result in accordance with the ordinary theory of continuous girders, in which the maximum of the reaction on a pier and of the negative moment are due to the same distribution of load. From this and other considerations, it follows that the rate $\frac{R}{R^1}$ is constant throughout the whole length of the girder, whatever may be the distribution of the load.

Once ascertained that $\frac{R}{R^1}$ is constant, the next step is to solve the equations deduced by (18), which is done by the process, already mentioned, of indeterminate coefficients, and with the assumption that the distance of the end of the girder to the first sloping cable is νd, d being the equal distance of the consecutive joints, except the middle part, whose length is l.

Owing to the symmetry of the system, the two series of indeterminate coefficients, necessary for the general case, are reduced to one. The expression of M_k for any distribution of load is:

$$M_k = -\frac{h}{a_k \delta_{2n}} \begin{cases} \delta_{2n-k} d^2 \Big\{ (C''_1 \nu + C'_2) + \sum_2^{k-1} (C''_s + C'_{s+1}) \delta_{s-1} \Big\} + \\ + \delta_{k-1} d^2 \Big\{ (C''_{2n} + C'_{2n+1} \nu) + \sum_{k+1}^{n-1} (C''_s + C'_{s+1}) \delta_{2n-s} \\ \qquad + \sum_{n+2}^{2n-1} (C''_s + C'_{s+1}) \delta_{2n-s} \Big\} \\ + \delta_{k-1} l (\{C''_n d + C'_{n+1} l) \delta_n + (C''_{n+1} l + C'_{n+2} d) \delta_{n-1} \} \end{cases} \qquad (20)$$

The quantities belonging to each single bay are then separated in this expression in order to ascertain the influence of each. On examining the successive values of the series δ, it appears, first, that their numerical value increases from δ_1 to δ_{2n}; and then, that

while $\delta_1 \; \delta_2 \; . \; . \; . \; \delta_{n-1}$ are always positive, $\delta_n \; \delta_{n+1} \; . \; . \; . \; \delta_{2n}$ can either be positive or negative, their sign depending upon the quantity

$$a_{n+1} = 3\,c\,\mathrm{H}\,t^2_n - l^2\,h \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

being positive or negative.

If this quantity is positive, then the numbers δ are also all positive. The consequences of this property are the following:—

1st. If a_{n+1} is negative, (max $-$) M_k takes place by loading the $(n + 1)$ bays at the left, and also the middle portion l, and consequently (max $+$) M_k corresponds to the complementary distribution of load.

2nd. If a_{n+1} is null or positive, (max $-$) M_k takes place when the girder is entirely loaded; then (max $+$) $\mathrm{M}_k = o$.

Consequently the quantity a_{n+1} may be termed the fulcrum of the question relating to the influence of the moving load on the systems analysed.

Now the sign of a_{n+1} evidently depends on being (21)—

$$3\,c\,\mathrm{H}\,t^2_n \lesseqgtr l^2\,h \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

that is, it depends on the value of the rate $\frac{\mathrm{H}}{h}$ between the depth of the elastic girder and the height of the suspension towers.

It appears, then, that a proper choice of the rate $\frac{\mathrm{H}}{h}$ is necessary as having an important bearing on the greater or less flexibility of the system, the distribution of load corresponding to (max $-$) M_k, and hence the degree of rigidity of the two combined structures depending essentially on the said rate. The expression (21) being simple, it appears easy to choose *à priori* a convenient depth of the girder in relation to the height of the towers.

It does not seem necessary that a_{n+1} should be positive. A sufficient degree of rigidity is acquired by making $a_{n+1} = o$, and even this limit should only be realised for railway bridges, while for ordinary road bridges it would be sufficient to assume for a_{n+1} a negative value not far from zero.

If $a_{n+1} = o$, then from (21)—

$$\frac{\mathrm{H}}{h} = \frac{1}{3\,c}\left(\frac{l}{t_n}\right)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

l being comprised between $\frac{1}{3}$ and $\frac{2}{3}$ of the total span L.

Taking now into consideration, the principal suspension bridges

of the system, erected in America, it appears that in the Niagara bridge of 1855, which is undoubtedly the most rigid, and the only one constructed for railway use, the rate $\frac{H}{h}$ adopted by Mr. Roebling is nearly equal to the value deduced by making $a_{n+o} = o$, being $\frac{H}{h} = 0\cdot303$ mètre instead of $0\cdot363$ mètre.

In the other bridges the proportion is inferior to the one deduced from (33); hence their rigidity is proportionately less.

6. The necessity for the principal elements of the system being well proportioned to attain sufficient rigidity will also appear from the following considerations. As the lower ends of the radiating ropes are to be connected by a horizontal tie, in order to neutralise the thrust or horizontal component of the tension along the ropes, the equilibrium of the articulated system requires that the sum of the horizontal components should be null. But any irregular distribution of the moving load will produce a horizontal thrust on one side different from that on the other, which difference must necessarily be supported by the girder. Hence, if the girder is not rigid enough, the load on one side will depress that side, but will raise the other, an effect similar to that which takes place in an elastic arch partially loaded. The consequence is that the inclined ropes towards the unloaded side, not being able to resist thrust, will be deflected. If the difference between the movable load and the permanent one is small, the compression on the ropes of the unloaded side will be so trifling as to prevent their being deflected. But the moving load, as for instance on a railway bridge, may be considerable when compared to the permanent weight; hence the necessity of providing a bridge of sufficient rigidity.

By making $a_{n+1} = o$, the theory indicates that the moment of flexure M_k is negative for any distribution of the rolling load; consequently the stress on the inclined ropes is always tension. In this case the difference of intensity between the stresses of two equidistant ropes will always be small; the reaction of the girder necessary to equilibrate the consequent difference of horizontal thrust must also be small. In the Niagara bridge, for instance, in which the condition $a_{n+1} = o$ is nearly fulfilled, it would be impossible, whatever may be the position of the travelling train, for any inclined rope to be deflected.

On the other hand, in the suspension bridge over the Niagara Falls, erected in the year 1869, for the exclusive use of foot passengers, where the unsupported middle portion of the girder is the half of the whole span, 386 mètres, the depth of 2 mètres given

to the girders would be insufficient if the bridge had to be crossed by vehicles.

To prevent the rise of one side of the truss, when loaded, over the other, the engineer of this bridge has wisely introduced a number of guy lines under the girders, connecting them at many points with the abutments.

To complete this part of the theory the Author has taken into consideration a discontinuous load on a single bay of the girder, a research which is of practical importance only for the middle part l of the same. The value of a_{s+1} is also, under this point of view, the key of the solution. If it is negative the load must extend only to a certain part of l to produce in a given point the maximum moment; while, if a_{s+1} is positive, the maximum moment is produced by the bay being all loaded.

7. In the first two parts of the theory, which have been summarily recapitulated, the object of the Author has been to ascertain the conditions of equilibrium resulting from the combination of the articulated with the elastic system. There remains now to be examined the further combination of these two parts with the third and principal part formed by the suspension cable. The research, it is well to state, can only be approximate, as the question would otherwise be extremely complicated. The point in view being essentially the practical application of results, the Author refers to the approximate formulæ (14) (16) (17) which seem to be sufficiently exact.

The curve of equilibrium of a cable of constant section supporting only its own weight is a catenary, while if the load is uniformly distributed over the chord it is a parabola. Therefore, if the two different loads are contemporary, the curvature of the cable must be a special one partaking of the two loads mentioned. But as the weight of the cable can only be a fraction of the entire load, it may be, as it is generally, admitted that the curve of equilibrium is a parabola.

Let the origin be taken in the left suspension point, and let x y be the horizontal and vertical co-ordinates of any point of the cable. Let p be the load per mètre of the horizontal chord, L the span, and h the depression of the vertex of the cable below the points of suspension. The rise h of the cable is taken as equal to the height of the towers above the neutral axis of the girder; it is a condition introduced to simplify the calculations; hence the vertex of the cable is tangential to the axis of the girder. The equation of the curve, before flexure is—

$$y = \frac{4\,h}{\mathrm{L}^2}\,x\,(\mathrm{L} - x) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

After the deformation produced by the loads, from which the weight of the cable must be deducted, as the flexure produced by the same takes place when the cable is put up, let h^1 and y^1 be the values of h and y; the equation or curvature will then be—

$$y^1 = \frac{4\,h^1}{L^2}\,x\,(L - x) \qquad (25)$$

Let $h^1 - h = s_c$ be the deflection of the cable in the middle, and $y^1 - y = s^1_x$ the deflection in the point x, y, then, from (24), (25)

$$s^1_x = \frac{4}{L^2}\,x\,(L - x)\,s_c \qquad (26)$$

In order to find s^1_x the ends of the cable are supposed fixed, under the consideration that the change of length of the external portions of cable or anchoring chains produced by the load must be compensated during construction by a proportional rise of the vertex, and because the deformations produced by a change in the initial temperature are not here considered. The approximate length L^1 of the parabola, whose chord is L, is—

$$L^1 = L + \frac{8\,h^2}{3\,L} - \frac{32}{5}\,\frac{h^4}{L^3} + \&c.,$$

or, with sufficient accuracy:

$$L^1 = L + \frac{8\,h^2}{3\,L} \qquad (27)$$

As the length of the chord is invariable, and as $d\,(h) = s_c$, it follows that

$$d\,(L^1) = \frac{16}{3}\,\frac{h}{L},$$

hence:

$$s_c = \frac{3}{16}\,\frac{L}{h}\,d\,(L^1) \qquad (28)$$

The cross section of the cable being constant, while the stress varies from one point to another, the consequence is that the specific stress cannot be constant. Let a be the angle between the tangent in the point $x\,y$ with the horizon, and T the tension in the same point, being Q the constant horizontal thrust. Then—

$$T = \frac{Q}{\cos a},\ Q = \frac{p\,L^2}{8\,h}\cos a = \frac{1}{\sqrt{\left\{1 + 16\,\frac{h^2}{L^4}(L - 2\,x)^2\right\}}} \qquad (29)$$

Consequently

$$T = \frac{p\,L^2}{8\,h}\sqrt{\left\{1 + 16\,\frac{h^2}{L^4}\,(L - 2\,x)^2\right\}}. \qquad (29^1)$$

If an element $d\,s$ of the curve is subject to the elongation $d^2\,s$, then, from a well known formula,

$$d^2\,s = \frac{d\,s}{E_c\,F_c}\,\frac{Q}{\cos a},$$

F_c being the section of cable, and E_c the coefficient of elasticity of its material, and

$$d\,s = \frac{d\,x}{\cos a},$$

the total variation $d\,(L^1)$ of the cable's length will be:

$$d\,(L^1) = \frac{2\,Q}{E_c\,F_c}\int_o^{\frac{L}{2}} \frac{1}{\overline{\cos}^2\,a}\,d\,x,$$

substituting the value of $\overline{\cos}^2\,a$, and integrating between the given limits,

$$d\,(L^1) = \frac{Q}{E_c\,F_c}\left\{L + \frac{16\,h^2}{3\,L}\right\},$$

when, from (27),

$$d\,(L^1) = Q\,\frac{2\,L^1 - L}{E_c\,F_c},$$

otherwise, by putting $\frac{Q}{F_c} = R_c$ it follows that

$$d\,(L^1) = \frac{R_c}{E_c}\,(2\,L^1 - L) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (30)$$

By introducing this value in (28)

$$s_c = \frac{3}{16}\,\frac{L}{h}\,\frac{R_c}{E_c}\,(2\,L^1 - L) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (31)$$

and finally, from this and (26) it follows that

$$s^1{}_x = \frac{3}{4}\,\frac{R_c}{E_c}\,\frac{2\,L^1 - L}{h}\,x\,\frac{(L - x)}{L} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (32)$$

8. An approximate value of the vertical flexure of the girder in the middle of its length has already been given (17); still, in order to render more explicit the influence of the quantity a_{n+1} (21) on the flexibility of the structure, the Author proceeds as follows:

Considering the middle portion l of the girder, unsupported by the ropes, uniformly loaded by q per mètre, being I_m the constant moment of inertia, the differential equation of the deformed axis is—

$$E_m\,I_m\,\frac{d^2\,y}{d\,x^2} = M_n + q\,\frac{l}{2}\,x - q\,\frac{x^2}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

which, as already stated, has two points of contrary flexure, determined by the condition

$$E_m I_m \frac{d^2 y}{d x^2} = o.$$

Introducing for M_n the approximate value (16), and calling the distance between the points mentioned l_o, then—

$$l_o = 2\,l \sqrt{\frac{1}{6}} = 0 \cdot 816\, l.$$

Integrating (33), and deducing the constant, which is—

$$C = -\frac{1}{24} q\, l^3 - M_n \frac{l}{2},$$

it follows that

$$E_m I_m \frac{d y}{d x} = M_n \left(x - \frac{l}{2} \right) + q \frac{l}{4} x^2 - q \frac{x^3}{6} - q \frac{l^3}{24}.$$

Integrating again, calling y_n the deflection of the origin ($x = o$) where the moment of inertia is I_n, the preceding becomes:

$$E_m (I_m y_m - I_n y_n) = M_n \left(\frac{x^2}{2} - l \frac{x}{2} \right) + q \frac{l}{12} x^2 - q \frac{x^4}{24} - q \frac{l^3}{24} x.$$

The deflection y_n is produced by the elongation of the nth sloping rope, and the corresponding value is given by (2) or

$$y_n = \frac{R_t}{E_t h} t_n^2,$$

where E_t and R_t are the coefficient of elasticity and the maximum specific stress convenient to the wire of the ropes.

By substituting this value in the above equation, and calling the deflection in the middle of the girder s_m, the value of s_m is:

$$E_m I_m s_m = - M_n \frac{l^2}{8} - \frac{5}{384} q\, l^4 + R_t I_n \frac{t_n^2 E_m}{h E_t}.$$

Calling R_n the maximum specific stress in the girder at the point where the moment is M_n, being H the constant depth of girder, then, from the general equation between the moment of resistance and the moment of rupture,

$$R_n = M_n \frac{H}{2 I_n},$$

which, introduced in the preceding equation, together with the approximated value of M_n (16) becomes:

$$E_m I_m s_m = -\frac{3}{384} q\, l^4 - \frac{1}{48} q\, l^2 \frac{H}{h} t_n^2 \frac{R_t}{R_n} \frac{E_m}{E_t}.$$

Considering now that in absolute value, that is, not considering the sign of the moments, $M_n = \frac{1}{2} M_m$, and also that the moment of inertia is constant along the span l, being I_m, it follows that R_n will be $\frac{1}{2}$ R_m. By substituting this value and remembering (4) that

$$\frac{E_m}{R_m} \cdot \frac{R_t}{E_t} = c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (34)$$

the preceding gives:

$$E_m I_m s_m = -\frac{1}{384} q \frac{l^2}{h} \left\{ 3\, l^2 h + 16\, c\, H\, t_n^2 \right\} \quad . \quad . \quad . \quad (35)$$

The quantity a_{n+1} must now be recalled (21); or

$$a_{n+1} = 3\, c\, H\, t_n^2 - l^2 h.$$

Remembering that if this quantity is null or positive, (max −) M_t takes place when the girder is completely loaded; and that the girder possesses a sufficient degree of rigidity if a_{n+1} is null, or else a small negative value, then:

$$H = \frac{l^2 h}{3\, c\, t_n^2} k \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (36)$$

or—

$$a_{n+1} = l^2 h\, (k - 1),$$

being k a fraction not far from unity, and whose maximum is $k = 1$. Putting the value (36) in (35)—

$$s_m = -\frac{3}{384} q \frac{l^4}{E_m I_m} \left\{ 1 + 1 \cdot 78\, k \right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (37)$$

which, for $k = 0 \cdot 6$ nearly, gives the approximate value (17)—

$$s_m = -\frac{1}{64} q \frac{l^4}{E_m I_m}.$$

Putting now in (36) the value

$$I_m = M_m \frac{H}{2\, R_m},$$

and for M_m the value (14) the deflection becomes:

$$s_m = -\frac{3}{16} \frac{l^2}{H} \frac{R_m}{E_m} \left\{ 1 + 1 \cdot 78\, k \right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (38)$$

which can be given under another form, in order to show more clearly the influence of k. Putting the value of H (36), the last gives:

$$s_m = -\frac{9}{16}\frac{c}{h}t_n^2 \cdot \frac{R_m}{E_m} \cdot \left\{\frac{1}{k} + 1 \cdot 78\right\}\frac{1}{k} \quad . \quad . \quad . \quad . \quad . \quad (39)$$

which shows how s_m decreases by increasing k, that is to say, the rate between the real depth of the girder, and the depth which is deduced by making $a_{n+1} = o$.

9. The first condition which must be fulfilled, as arising from the combination of the cable with the girder, is the following: whatever may be the distribution and the intensity of the load, the deflection of the vertex of the cable must be equal to that of the middle of the girder. That is to say, $s_m = s_c$; or by (31) and (37):

$$\frac{R_c}{E_c}\frac{L}{-}(2\,L^1 - L) = \frac{R_m}{E_m}\frac{l^2}{H}\left\{1 + 1 \cdot 78\,k\right\}.$$

Putting

$$\frac{E_c}{R_c} \cdot \frac{R_m}{E_m} = a \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (40)$$

the preceding equation gives—

$$h = \frac{H\,L}{a\,l^2}\left(2\,L^1 - L\right)\frac{1}{1 + 1 \cdot 78\,k}.$$

For the practical use of this formula, the approximation given by assuming $L^1 = L$ is sufficient: therefore—

$$h = \frac{H}{a}\left(\frac{L}{l}\right)^2\frac{1}{1 + 1 \cdot 78\,k} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (41)$$

10. A second condition to be fulfilled is that the depth of the girder H should not be less than the limit beyond which its own weight would produce the maximum allowable specific stress R_m in the booms, otherwise the girder would not contribute to the rigidity of the system, especially in its middle part, and as a static element it would be little more than a parapet. This condition is easily represented.

Let ω be the cross section of one of the flanges or booms of a girder in the middle of its length; then the volume of the two flanges together, for 1 mètre in length will be 2 ω, which will nearly be the complete volume of the portion of girder considered, because the shearing stress is null in the middle when the load is uniform, and always small under other conditions of load. Still, as it is necessary to complete the trellis, two diagonals at

least and a vertical rod must be introduced to join the booms. Then it may be admitted that the volume of these parts in the middle and for the length mentioned is about $\frac{2}{5}$ of the volume of a flange; assuming the diagonals to be inclined at 45°, and calling π the specific weight of the material, the weight of 1 mètre in length of the girder in the middle will be—

$$2 \cdot 40\, \pi\, \omega.$$

Recalling the approximate value (14) of M_m, then:

$$\omega = \frac{q}{12} \frac{l^2}{H} \frac{1}{R_m}.$$

Let q_o be the weight of a length of 1 mètre of girder, in the middle of its length, then from the two last expressions—

$$q_o = \frac{2 \cdot 40}{12} \pi \cdot q \cdot \frac{l^2}{H\, R_m},$$

and by putting—

$$\frac{q}{q_o} = n \qquad (42)$$

and deducing H—

$$H = 0 \cdot 20\, \pi \,.\, n \frac{l^2}{R_m}. \qquad (43)$$

the minimum value of which, for application, should be the corresponding $n = 1$, in which case the girder will only support its own weight; any other load would increase the stress in the booms beyond the limit R_m.

11. A third condition requires that every part of the combined structure should be so proportioned as to determine in the whole a state of sufficient rigidity. This condition has already been treated, and found to be represented by (36)

$$H = \frac{l^2 h}{3\, c\, t_m^2} k,$$

the maximum of k being $k = 1$, as already stated.

Equalising the three values of H (36), (41), (43), it follows that—

$$h\, a\, (1 + 1 \cdot 78\, k) \left(\frac{l}{L}\right)^2 = 0 \cdot 20\, \pi \,.\, n \frac{l^2}{R_m} = \frac{h}{3\, c} \left(\frac{l}{t_m}\right)^2 k.$$

The first and third of which give—

$$t_m^2 = \frac{k}{3\, c\, a} \frac{L^2}{(1 + 1 \cdot 78\, k)} \qquad (44)$$

The second and third—

$$t_n^2 = \frac{k}{0 \cdot 6\, c} \frac{h\, R_m}{\pi\, n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (45)$$

And from these two the following is deduced—

$$h = \frac{1}{5} \frac{\pi\, n}{a} \frac{L^2}{R_m} \frac{1}{1 + 1 \cdot 78\, k} . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (46)$$

The length of the longest inclined rope is given by—

$$t_n^2 = \left(\frac{L - l}{2}\right)^2 + h^2,$$

which, placed in (44) gives:

$$l = L - 2 \sqrt{\left\{\frac{L^2\, k}{3\, c\, a\, (1 + 1 \cdot 78\, k)} - h^2\right\}} \quad . \quad . \quad . \quad (47)$$

If the cable and the sloping ropes are both constructed of the same material, and if $R_t = R_o$, that is to say, if the maximum specific stress per square unit of section is also taken to be equal in both, or else if $\frac{E_o}{E_t} = \frac{R_o}{R_t}$, then by (34) and (40) is obtained $c\, a = 1$; hence—

$$l = L - 2 \sqrt{\left\{\frac{L^2\, k}{3\, (1 + 1 \cdot 78\, k)} - h^2\right\}} \quad . \quad . \quad . \quad . \quad (48)$$

And when the rate k is taken = 1—

$$l = L - 2 \sqrt{\left\{\frac{L^2}{8 \cdot 34} - h^2\right\}}.$$

12. The expressions just obtained contain the principal geometrical elements of the three combined structures, and the conditions which they must satisfy, in order that the whole may possess sufficient stability; therefore they enable convenient proportions to be assumed between the essential parts of the system.

Formula (46) gives—

$$L = 5\, a\, \{1 + 1 \cdot 78\, k\} \frac{R_m}{\pi} \left(\frac{h}{L}\right) \frac{1}{n}.$$

which enables the largest possible span to be deduced, or a practical limit of length consistent with the rigidity of the system, and with given limits of specific stresses in each structure.

In fact from the expression obtained, it appears that L increases by increasing k, and also that L is inversely proportional to n. Now the maximum of k is (36) $k = 1$, in which case the moments

of flexure of the girder are always of the same sign, and consequently the rope cannot be deflected; and the minimum value of n is also (42) $n = 1$, in which case the weight of the girder will, by itself, produce the maximum allowed stress per square unit of the given material. Putting then $k = n = 1$—

$$\max L = 13 \cdot 90 \, a \frac{R_m}{\pi} \left(\frac{h}{L} \right).$$

Suppose the case of a wrought-iron girder, then $\pi = 7800$ kilogrammes per cubic mètre, and $R_m = 8{,}000{,}000$ per square mètre of section, a limit of stress which should not be surpassed by the flanges or booms of an elastic girder. Then follows—

$$\max L = 14256 \cdot 40 \, . \, a \, . \left(\frac{h}{L} \right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (49)$$

For extraordinary spans the cables must be made of steel wire, like those adopted for the East River bridge; the rate between the coefficients of elasticity of steel and iron may be assumed at $\frac{5}{4}$, that is to say—

$$\frac{E_a}{E_m} = \frac{5}{4}.$$

Finally, the rate between the maximum specific stresses in the iron girder and the steel cable may be deduced by assuming the mean values corresponding to the limit of elasticity of both materials, or $R_m = 15$ and $R_a = 30$ kilogrammes per square millimètre. Then $\frac{R_m}{R_a} = 0 \cdot 50$; hence from (40)—

$$a = \tfrac{5}{4} \, . \, \tfrac{1}{2} = 0 \cdot 63.$$

Substituting this value in (49) it follows that:

$$\max L = 8981 \cdot 53 \left(\frac{h}{L} \right).$$

Taking $\frac{h}{L} = \frac{1}{10}$, a rate which has not been surpassed for large spans by any suspension bridge yet constructed, the result is:

$$\max L = 898 \cdot 15 \text{ mètres, or } 900 \text{ mètres.}$$

As for the length of the middle unsupported part of girder, it follows from (48) that $l = 276 \cdot 80$ mètres.

The maximum limit of practical span thus obtained is interesting from a singular coincidence. Mr. Malézieux[1] states that Mr.

[1] *Vide* "Travaux publics des Etats-Unis d'Amérique," p. 77.

Roebling, the inventor of the combined system under analysis, in a Report addressed to the Council of Administration of the East River Bridge Company, declares that the span of the new suspension bridges could be increased without danger to 900 mètres.

13. In order to appreciate by comparison the influence which the combination of the three structures has in relation to the maximum span, the Author proceeds to deduce a corresponding limit for an ordinary suspension bridge.

Let p be the load per mètre of chord, excluding the weight of the cable, ω the cross section of the cable, and π the specific weight of a cubic mètre of the material. The greatest tension in the cable will by (29^1) be obtained. Putting $x = o$—

$$T = (p + \omega\pi)\frac{L^2}{8h}\sqrt{\left\{1 + \frac{16h^2}{L^2}\right\}}.$$

Calling R the specific stress per square unit of cross section, it follows that—

$$R\omega = (p + \omega\pi)\frac{L^2}{8h}\sqrt{\left\{1 + \frac{16h^2}{L^2}\right\}},$$

from which—

$$\omega = p\frac{L^2}{8h}\frac{\sqrt{\left\{1 + \frac{16h^2}{L^2}\right\}}}{R - \frac{\pi L^2}{8h}\sqrt{\left\{1 + \frac{16h^2}{L^2}\right\}}}.$$

By putting $h = k^1 L$ and deducing L—

$$L = \frac{8\omega R k^1}{(p + \omega\pi)\sqrt{\{1 + 16\overline{k^1}^2\}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (50)$$

The required limit of span evidently corresponds to $p = o$; then—

$$\max L = 8\frac{R}{\pi} \cdot \frac{k^1}{\sqrt{1 + 16\overline{k^1}^2}},$$

which result is identical with that given by Navier.[1]

Taking R = 20 kilogrammes per square millimètre, $\pi = 7800$ and $k^1 = \frac{1}{10}$, then—

$$\max L = 2209 \text{ mètres.}$$

The conclusion is, that the condition of rigidity necessary for the new suspension bridges reduces to less than half the greatest possible span, corresponding to the rate of $\frac{1}{10}$ between the rise and chord of the cable.

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[1] *Vide* "Mémoire sur les Ponts suspendus." Paris, 1833, p. 175.

The comparison may also be made, by assuming in both cases the same value of h. Putting in the last expression $h = \frac{900}{10} =$ 90 mètres, which can be considered as a practical maximum, or $k^1 = \frac{90}{L}$, the result is—

$$L = 1500 \text{ mètres nearly.}$$

Consequently, at the limit of 900 mètres the girder would only bear its own weight against a given limit of maximum specific stress, and all the remaining load would be sustained by the cable. Beyond this limit the bridge could not be called rigid, and the load which the cable would be able to bear, besides its own weight, progressively decreases, until at the limiting span of 1500 mètres, together with the rise of 90 mètres, the extra load would be null, and its own weight would induce in the steel cable a stress of 20 kilogrammes for each square millimètre of cross section.

(*Paper No. 1684.*)

"On Fire-hydrants, with description of one in use at Halifax, N.S."

By Edward Henry Keating, M. Inst. C.E.

The most simple form of hydrant is a stand-pipe with one or more hose-couplings at the top, and a water valve at or near the base. If the valve is so arranged that, in the act of closing it, a waste-valve is opened, by which the stand-pipe will be drained or emptied of water, the apparatus in many situations will probably answer the purpose as well as some of the more costly appliances.

There are, however, some objections to this form of hydrant, especially in climates subject to frost and snow. If the locality is one where the thermometer at times falls many degrees below freezing point, and deep snow lies upon the ground for days or weeks together, the inconvenience and delay caused by the necessity of measuring to ascertain the position of the valve, and in digging through snow or ice to reach it, may be great; while during the time that these operations are being performed a conflagration may gain serious headway.

In such localities it becomes of the first importance to adopt some form of hydrant that can be at once got at and controlled by the firemen, without the necessity of searching either for its position, or for that of the valve by which it is regulated.

In design the chief matters needing attention are—

1. Simplicity as far as practicable.
2. That all the different parts be durable, not liable to derangement, and strong enough to withstand rough usage at the hands of inexperienced, careless, or excited men.
3. That it may be relied upon during frost, without the necessity of frequent inspection.
4. That the stand-pipe and valves be so proportioned as not to affect the free delivery of water to the nozzles.
5. That it may be easily removed for repairs or replaced.
6. Perfect drainage.

At Halifax during winter the maximum thermometer ranges between $+40°$ and $+60°$, and the minimum thermometer between $+20°$ and $-10°$ Fahrenheit; although at intervals of several

Fig : 6.

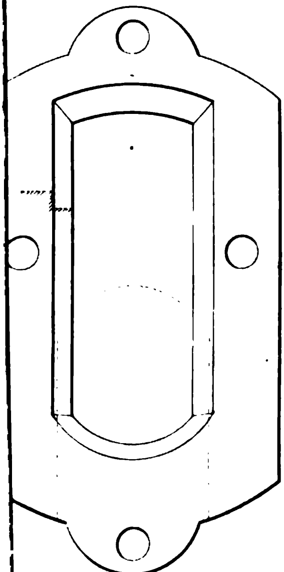


Fig : 7.

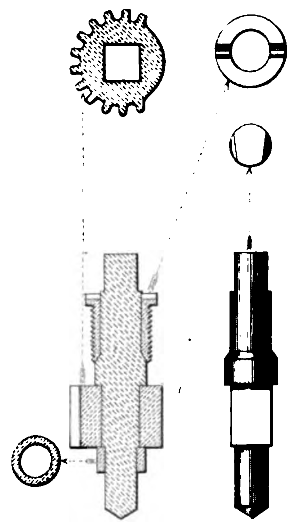


Fig : 5.

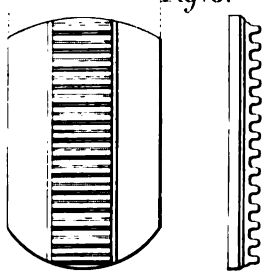
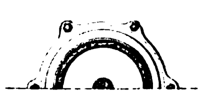


Fig : 4.



Half Sectional Plan at A.B.

Scale 1/16.

NOTE.

Figures 3, 5, 6 and 7 are drawn to 1/4 real size.

Iron.

Gun Metal.

THOS KELL & SON, LITH

years, the thermometer has been known to fall as low as −20°. The climate, being affected by the Atlantic and oceanic currents, is moist and changeable. Usually there are periods during which the atmosphere is clear and bracing, succeeded by a few days of rain, and sometimes fog. Snow sufficient to allow good sleighing often remains upon the ground for a few weeks at a time; while after the periodical changes from wet to dry and cold, the whole surface of the country is occasionally covered with a glaze of ice. Frost penetrates the ground to a depth of from 3 to 4 feet, and in clay soils to about 5 feet.

The water mains as a rule are laid at a depth of 5 feet from the surface of the street to the top of the pipe.

There are about three hundred hydrants in the city at distances apart varying from 250 to 450 feet, the usual interval being 300 feet. Most of these hydrants are of an old style, set in a brick well or chamber built for their reception below the foot-path adjoining the curb. In outward appearance they resemble in some respects Plate 16, Fig. 1, with the casing or frost jacket removed, but are dissimilar in detail and construction. The chamber is covered by a cast-iron plate provided with a hatch, by which access is gained to the bottom of the hydrant where it joins the branch from the main. This arrangement, although possessing some advantages and admitting of the easy removal of the hydrant, was considered by the Author objectionable for several reasons, principally on account of the difficulty and expense in keeping the valves free from ice, and the large iron sidewalk plate becoming smooth and dangerous.

From four to five men were constantly employed throughout the winter, whose daily duty it was to examine each hydrant, thaw out the ice from any which should be found frozen up, and to see that they were in proper working condition.

The hydrant, Fig. 1, was designed and adopted by the Author after a careful inspection of many others, and after consultation with practical men connected with the fire departments of Halifax and other Canadian cities. It is not claimed that all the details are original. The main valve and the rod-guide, which also forms the waste valve, Fig. 3, are the same as in an American hydrant known as "the Matthews' hydrant," and the gate, or cut-off valve, at each nozzle (Figs. 5, 6, and 7) is partly the invention of a local mechanic. The object of the latter contrivance is to allow the hose to be coupled to, or uncoupled from, one nozzle at any time, without interrupting the stream of water from the other. In the absence of some such arrangement it frequently happens during

a conflagration that only one nozzle can be utilised, and, in the experience of the Author, serious troubles have arisen between different authorities for the want of a similar provision.

The spring brass and leather attachment to the rod-guide (Fig. 3) forms the waste valve. There are two waste holes in the stand-pipe against which this valve works, the upper hole being $\frac{1}{2}$ inch and the lower $\frac{3}{16}$ inch in diameter. It was found necessary to provide this double waste on account of the lower and smaller hole, which was at first the only one, sometimes becoming choked with sediment, and it was not thought advisable to enlarge it, as considerable waste and consequent loss of pressure might result while the hydrant was in use. This would certainly be the case unless the main valve in each instance were screwed down to its full extent.

The main screw on the valve-rod is protected from the action of water and frost by a partition and stuffing-box. The frost-jacket is securely bolted to the iron seat, and when once set never need be removed; it forms a dead-air chamber which prevents the frost from reaching the main valve, and at the same time affords the means of easily removing the hydrant. Some hydrants provided with a similar frost-jacket are made to fit tightly upon the seat by a large screw turned at the base; but in the event of the slightest derangement to the thread of the screw the hydrant becomes useless. It was for this reason that the Author adopted a flange joint. The flanges are turned perfectly true, and a rubber diaphragm is made to fit into a dove-tailed groove on the stand-pipe flange, so that when the hydrant requires to be taken up there is no danger of the diaphragm remaining down to cause inconvenience. The hydrant can be readily removed by unscrewing the nuts just above the pavement, and another can as readily be inserted. The effect of tightening up the nuts is to compress the diaphragm between the flanges at the base.

Many of these hydrants have now been in use for the last two years with scarcely a case of stoppage or derangement; they are frost proof, and are believed by the Author to be more reliable and suitable to the climate than any that have yet come to his notice. They are manufactured at a cost of \$66·50 each, complete and ready to be set up. Each hydrant is tested by hydraulic pressure to 200 lbs. on the square inch before leaving the workshop.

The communication is accompanied by a drawing, from which Plate 16 has been prepared.

(*Paper No. 1702.*)

"The Regulation of the Waters of the Jura."

By C. DE GRAFFENRIED, Engineer-in-Chief of the Works, Berne.

THE country extending to the foot of the eastern slope of the Jura, from Entre-Roches to Solothurn, formerly presented vast stretches of marsh and of land frequently under water. These marshes and water meadows constituted, under the title of the "Grand Marais," the greater part of the country comprised between lakes Morat, Neufchâtel, and Bienne, and extended also along the Orbe up stream from lake Neufchâtel to Entre-Roches, and down-stream along the Thiele and the Aar as far as Solothurn. In the cantons of Berne, Fribourg, Solothurn, Neufchâtel, and Vaud, these occupied a superficies of about 190 square kilomètres, which was either not under cultivation, or of which the meagre produce was frequently destroyed by inundations.

This state of things was the result of the irregular courses of the rivers, of the absence of any current in the Thiele between Nidau and Büren, and of the consequent elevation of the surface of the lakes. The Aar, swollen by the waters of the Sarine, covered (including its shingle banks) a large strip of land below Aarberg, and fell almost perpendicularly into the Thiele, near Meyenried. The latter river leaving lake Bienne with a lesser inclination, its waters became in consequence forced up stream against the natural current. This action of the Aar, the insufficiency and inequalities of the bed of the Thiele, and, above all, a sort of bar which existed above Brugg, had the effect of hindering the movement of the waters of lake Bienne, and therefore of those of lakes Neufchâtel and Morat, and of considerably raising their level. Thus the neighbouring country, saturated to a great distance from the river banks, was always maintained in a marshy state, and on the occasion of floods became a vast lake.

The object of the undertaking known as "The Regulation of the Waters of the Jura" is to improve the present condition of the rivers, particularly the Thiele and the Aar, by training their banks, and thus to lower the level in the lakes. The enterprise consists of—

1st. The derivation of the Aar from Aarberg on lake Bienne by a canal from the Rappenfluh to Hagneck.

2nd. The formation of a canal of sufficient capacity to convey the united volumes of the Aar and the Thiele, from their outlet on the lake, to a point below the junction of the two rivers.

3rd. The regulation of the Upper Thiele and of the Lower Broye, so as to facilitate the flow of the water from lakes Neufchâtel and Morat into lake Bienne.

To this must necessarily be added the opening of canals for the drainage of the marshes.

The main feature of the project, which is due to Colonel La Nicca, of Coire, is to constitute lake Bienne the regulator of the river Aar, to make it the receptacle of any gravel that may be brought down, and at the same time to neutralise the effect of the junction of this river with the Thiele at Meyenried.

The estimated cost of the works is as follows:—

	£
1. Canal from Aarberg to Hagneck	148,000
2. „ Nidau-Büren	196,000
3. „ Upper Thiele	58,400
4. „ Broye	29,600
5. Works between Büren and Solothurn	41,200
6. Administration, engineering, and contingencies	86,800
	£560,000

The Swiss confederation contributes £200,000 to this amount. The remainder is furnished by subsidies from the Cantons interested, equal to the increased value of the land.

The Aarberg-Hagneck canal, which will carry the waters of the Aar to lake Bienne will be 5·15 miles long, with a fall of 1·4 in 1,000 to the Hagneck cutting, 4½ miles distant, and a fall of 3·75 in 1,000 for the remainder of its course. The canal will accommodate a maximum discharge of from 38,000 to 43,000 cubic feet per second. The width is 196 feet at the bottom for the greater part of the length, contracted to 131 feet in that part having a fall of 3·75 per thousand. The depth varies between 20 and 23 feet. The banks of the canal have a slope of 3 to 2, and are pitched with limestone, laid dry, and having a toe of the same material. This system of defence obtains for a length of 2·4 miles where the canal traverses compact gravel. In the marshes, where the soil is turf on clay, the banks were first consolidated by a layer of gravel, and bundles of fascines, 2 feet 7 inches in diameter, were laid along the bottom before depositing the stone pitching. At a distance of 52 feet beyond each bank of the canal

there is a secondary bank 20 feet wide at the top, which is elevated 24½ feet above the bottom of the canal, that is to say, out of reach, by 3 feet, of the highest known floods. These secondary embankments form at the same time occupation roads.

The most important work is the cutting through the Colline de Hagneck, which divides the marshes of lake Bienne. This cutting, the sides of which are in some parts nearly 100 feet high, will involve, for a distance of only 984 yards, 1,262,600 cubic yards of excavation in hard rocky marl. The total excavation for the Aarberg-Hagneck canal is 5,035,800 cubic yards. Except in the case of the Hagneck cutting, which had to be almost entirely made by artificial means, only a longitudinal trench (cunette), from 23 to 26 feet wide, cubing 2,082,800 yards, has been excavated. The erosive action of the water is counted upon to accomplish the remainder. To regulate this anticipated erosion, a weir has been constructed at the head of the canal near Aarberg, provided with sluices, allowing of the discharge of the desired volume of water. The result of the erosion in 1879 was very satisfactory. The water transported into lake Bienne 235,440 cubic yards, effecting a corresponding increase in the dimensions of the canal.

The Nidau-Büren outlet canal from lake Bienne is 7½ miles long, and has a fall of 1 in 5,000. The cross section is trapezoidal, the width at the bottom being 216½ feet, and the height ranging from 20 to 23 feet. The banks are inclined at 2 to 1. They are defended by dry stone pitching to the level of ordinary floods; above the slopes are wattled and grassed. This cut having considerable capacity, and the surrounding country being well elevated, there is no necessity for secondary banks as in the case of the Hagneck canal. The excavation amounts to 5,091,328 cubic yards, of which rather less than two-thirds have been removed by steam dredgers, and the remainder by hand labour and natural erosion, the latter action being only counted upon to the extent of 147,800 cubic yards.

The regulation of the Upper Thiele and of the Lower Broye consists only of training, deepening, and cleaning out the beds of those rivers, so as to allow lakes Neufchâtel and Morat to participate in the lowering of the level produced in lake Bienne by the construction of the Nidau-Büren and Hagneck canals.

The Upper Thiele has a length of 4½ miles, and a uniform fall of 0·16 in 1,000. The width, as regulated, is 98½ feet, the depth 19½ feet, and the banks are sloped at 2 to 1.

The Lower Broye, between lakes Neufchâtel and Morat, is 5·2 miles long, in which distance it falls 1 foot. The width at the

bottom is $52\frac{1}{2}$ feet, the depth 16 feet 5 inches. At the head of the canals in the lakes moles are constructed.

These works, begun in 1869, are now (January 26, 1880) approaching completion. The Nidau-Büren canal is not yet quite finished, the last cut near Büren having still to be made. Notwithstanding this, it has already lowered the level of lake Bienne by 7·87 feet. The success of the works is therefore assured, and it only remains to complete them.

(*Paper No. 1705.*)

"The River Nile."

By Benjamin Baker, M. Inst. C.E.

This Paper may be considered as supplementary to, and where conflicting as in substitution of, the article on the same subject in Mr. Beardmore's 'Manual of Hydrology.' It is based chiefly upon Egyptian Government documents, the returns of Mr. Fowler's assistant engineers in Egypt, and the Author's own observations.

The height of low Nile above the mean sea-level at Alexandria has been ascertained by levelling at the following places:—

	Height in Feet.	Distance in Miles.
Rosetta Mouth	..[1]	..
Kafr-el-Zaiat	4·3	36
Grand Barrage	33·5	110
Cairo	39·5	126
Benisouef	75	200
Minieh	107	285
Siout	146	380
"First Cataract" (below)	303	714
" " (above)	319	716
Wady Halfa	392	964
Hannek	659	1,205
Guerendid	745	1,418
Oum Deras	907	1,468
El Kab	935	1,490
Junction of the Atbara	1,148	1,671
Shendy	1,165	1,756
Khartoum, junction with the Blue Nile	1,212	1,870

[1] The maximum known variation in the sea level is from − 1·57 feet to + 2·32 feet.

At high Nile the surface slope of the river averages about 5 inches per mile, except at the cataracts or rapids. The Grand Barrage is situated at the apex of the Delta, where the river diverges into two branches. For a distance of 30 miles below the barrage the surface slope of the western, or Rosetta branch, is 5½ inches per mile; and of the eastern, or Damietta branch, 4½ inches. The latter branch is 13 miles longer than the former,

and, as will be shown hereafter, by far the larger volume of water is conveyed down the shorter branch.

The "first cataract" of the Nile is situated at Assouan. Between Assouan and Wady Halfa the river is navigable, but there are fourteen more or less serious obstructions, such as rocks in the channel, and shifting sands. Between Wady Halfa and Oum Deras there are eighteen cataracts; beyond that to El Kab a continuous series of rapids, and from thence to Shendy three more cataracts, after which the Nile becomes navigable as far as Khartoum.

In the portions of the river where equilibrium is established between the velocity of the current and the stability of bed, the sectional areas, both at low and high Nile, are remarkably constant, at widely distant points. Thus near Kohé, about 1,200 miles up the river, the area at low Nile is 14,000 square feet, and at high Nile, 71,000 square feet; whilst at Queremât, about 56 miles above Cairo, the respective areas are 13,000 and 74,000 square feet; and at the barrage, 16 miles below Cairo, 12,500 and 72,000 square feet.

By far the most characteristic feature and interesting fact connected with the Nile is the singular uniformity in the date of commencement and the extent of its annual rise. The whole agricultural arrangements of the country hinge upon this, and the productions of the soil are so dependent upon the last few feet rise of the Nile, that with a rise of but 17 feet 6 inches famine is inevitable, and even of 19 feet 6 inches but too probable, whilst between 20 feet and 23 feet the supply of water is barely sufficient, though at 26 feet it is excessive. Beyond the latter height famine again threatens, because the salts in the soil are carried to the surface by the upward filtration of the river water, and the land becomes utterly unfit for cultivation until the salts have been washed away by a succeeding inundation. It must be observed that the surface of the land adjoining the river banks is about 17 feet above low water, and that it falls away from the river at the rate of about 5 inches per mile. Hence, with a 28-feet rise, such as occurred in 1874, the head for filtration is at least 11 feet; and although the river banks may be kept sound by the labour of a hundred thousand men, the water readily finds its way through the porous soil, and floods the land with a noxious solution of calcareous and magnesian salts and alkaline chlorides.

The height of the Nile has been recorded at Rhoda from time immemorial; but unfortunately the coudees of the nilometer are not all of the same length, so the returns have often misled

European engineers. The last few feet rise of the flood are obviously of far greater importance than the first, and this fact finds expression at Rhoda by the coudees gradually becoming shorter. As the height of the high Nile is not infrequently given in "The Times," as in the Egyptian newspapers, in coudees, or pics, and kerats (of which there are 24 to the coudee), it may be useful to state that the following equation expresses approximately the corresponding height in feet above low water:—

Height in feet = 1·52. (Height in coudees − 7 coudees 11 kerats.)

The Egyptian Government engineers have translated into French the Arabic measurements of the high Niles occurring between 1825 and 1874, and the following are the results in feet:—

1825–34	19·0	23·0	22·0	21·0	25·0	21·8	22·2	21·4	18·8	23·8
1835–44	19·4	20·4	19·0	21·0	22·0	25·2	25·0	25·2	22·0	21·6
1845–54	20·8	24·8	23·3	25·3	25·3	21·2	25·5	20·8	25·5	24·8
1855–64	20·3	25·5	21·3	21·0	20·8	25·2	26·2	23·2	26·6	19·6
1865–74	23·1	27·4	21·2	19·3	27·6	26·1	24·2	25·2	20·6	28·0

The earliest day on which the Nile commenced to rise in any of the preceding years was on the 10th of June, 1852, and the latest on the 10th of July, 1859. The earliest high Nile occurred on the 27th of August, 1868, and the latest on the 20th of October, 1872.

For some years past the daily height of the Nile has been recorded at the barrage, on a nilometer graduated to mètres—a much more convenient unit than the varying coudee. The Author has plotted diagrams of the heights for a series of years, and selects those for the years 1868, 1869, and 1870 as the most characteristic and interesting. To fully appreciate the identity of the phenomena exhibited each year—the first rapid rise, the slight halt, the final rise, and the relatively slow ebb to low Nile level, it is necessary to plot the diagrams on a large scale, and the original readings are therefore given to enable this to be done. As the unit of measurement and the calendar are immaterial, the Author, to avoid errors in reduction, retains the metric measures and the Coptic calendar, remarking merely that the Coptic year consists of twelve months of thirty days, and a complementary month of five days, and that the first day of the year 1585 corresponds to the 11th September 1868.

HEIGHTS of the NILE in MÈTRES, on the BARRAGE NILOMETER, from the LOW NILE of 1868 to the LOW NILE of 1871.

COPTIC YEAR 1584.

Months.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29
Baouna .	..	..	..	..	..	..	..	..	..	..	0·59	0·60	0·60	0·60	0·64
Ahbeeb .	0·66	0·73	0·81	0·92	1·32	1·42	1·58	1·55	1·79	2·00	2·40	2·50	2·75	2·93	3·10
Missra .	3·48	3·94	4·24	4·24	4·24	4·24	4·75	5·65	5·73	5·70	5·83	5·89	5·75	5·70	5·75
Nasi . .	5·75	5·63	5·58	..	..	..	..	..	..	..	..	..	..	..	..

COPTIC YEAR 1585.

Months.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29
Tout . .	5·56	5·52	5·48	5·48	5·48	5·48	5·58	5·55	5·55	5·52	5·50	5·48	5·40	5·35	5·33
Baba . .	5·30	5·15	5·05	4·95	4·90	4·79	4·75	4·70	4·60	4·38	4·28	4·24	4·20	4·12	4·05
Hatour .	3·95	3·87	3·80	3·70	3·68	3·65	3·62	3·50	3·35	3·30	3·23	3·18	3·15	3·08	3·04
Kyak .	3·00	2·90	2·85	2·80	2·78	2·75	2·72	2·70	2·68	2·65	2·60	2·56	2·52	2·50	2·48
Touba .	2·45	2·40	2·30	2·22	2·20	2·15	2·07	2·00	1·95	1·85	1·75	1·70	1·60	1·12	1·10
Emshir .	1·10	1·10	1·10	1·10	1·09	1·05	1·00	0·98	0·95	0·93	1·40	1·38	1·35	1·32	1·30
Barmahat	1·28	1·25	0·80	0·80	0·78	0·78	0·76	0·75	0·74	0·74	0·72	0·71	0·70	0·70	0·69
Barmouda	0·68	0·68	0·67	0·66	0·66	0·65	0·62	0·60	0·59	0·57	0·56	0·55	0·55	0·54	0·53
Bashams .	0·52	0·51	0·50	0·49	0·48	0·48	0·47	0·46	0·45	0·45	0·45	0·44	0·44	0·42	0·47
Baouna .	0·44	0·44	0·44	0·42	0·42	0·40	0·52	0·55	0·55	0·55	0·38	0·45	1·23	1·45	1·60
Ahbeeb .	1·85	2·15	2·25	2·25	2·25	2·25	2·29	2·35	2·45	2·57	2·63	2·66	3·08	3·65	4·08
Missra .	4·43	4·68	4·89	5·16	5·35	5·49	5·67	5·82	5·90	5·97	6·02	6·15	6·20	6·25	6·27
Nasi . .	6·35	6·40	6·47	..	..	..	..	..	..	..	..	..	..	..	..

COPTIC YEAR 1586.

Months.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29
Tout . .	6·50	6·60	6·65	6·75	6·85	6·98	7·00	7·02	7·05	7·07	7·05	7·10	7·20	7·30	7·40
Baba . .	7·74	7·92	7·95	7·75	7·60	7·50	7·40	7·29	7·20	7·09	7·00	6·90	6·75	6·60	6·40
Hatour .	6·30	6·15	6·05	5·90	5·85	5·45	5·40	5·58	5·55	5·53	5·50	5·40	5·35	5·25	5·22
Kyak .	5·10	5·03	4·90	4·83	4·72	4·62	4·50	4·37	4·25	4·13	4·00	3·90	3·82	3·80	3·80
Touba .	3·75	3·73	3·79	3·67	3·65	3·63	3·60	3·58	3·57	3·55	3·51	3·47	3·40	3·30	3·15
Emshir .	3·09	3·09	3·05	3·00	3·00	2·85	2·85	2·80	2·78	2·76	2·75	2·65	2·60	2·57	2·53
Barmahat	2·50	2·47	2·45	2·40	2·37	2·35	2·30	2·25	2·17	2·10	2·02	1·95	1·86	1·72	1·60
Barmouda	1·52	1·40	1·40	1·38	1·35	1·33	1·33	1·30	1·25	1·25	1·23	1·22	1·21	1·20	1·18
Bashams .	1·17	1·16	1·15	1·13	1·10	0·70	0·70	0·69	0·68	0·65	0·65	0·63	0·62	0·62	0·60
Baouna .	0·58	0·57	0·56	0·55	0·55	0·54	0·53	0·53	0·52	0·50	0·51	0·52	0·54	0·55	0·55
Ahbeeb .	0·55	0·62	0·75	1·00	1·60	1·75	2·15	2·50	2·75	3·25	3·88	4·15	4·25	4·39	4·75
Missra .	5·42	5·90	6·20	6·32	6·40	6·40	6·40	6·50	6·50	6·50	6·60	6·62	6·65	6·68	6·75
Nasi . .	6·80	6·80	6·82	..	..	..	..	..	..	..	..	..	..	..	..

COPTIC YEAR 1587.

Months.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29
Tout . .	6·88	6·95	7·10	7·25	7·25	7·31	7·32	7·30	7·25	7·23	7·23	7·25	7·25	7·30	7·37
Baba . .	7·45	7·53	7·55	7·48	7·43	7·40	7·41	7·42	7·33	7·27	7·17	7·09	7·00	6·85	6·85
Hatour .	6·70	6·55	6·30	6·13	6·05	5·95	5·75	5·75	5·55	5·40	5·38	5·25	5·25	5·15	5·12
Kyak .	5·10	5·05	4·85	4·62	4·50	4·40	4·34	4·30	4·25	4·22	4·15	4·08	4·04	4·00	3·95
Touba .	3·82	3·79	3·78	3·76	3·74	3·70	3·66	3·64	3·60	3·58	3·55	3·54	3·50	3·43	3·40
Emshir .	3·35	3·34	3·32	3·29	3·26	3·20	3·16	3·14	3·12	3·09	3·05	3·00	2·95	2·91	2·88
Barmahat	2·84	2·82	2·79	2·76	2·73	2·65	2·57	2·53	2·48	2·40	2·39	2·33	2·28	2·25	2·23
Barmouda	2·23	2·21	2·21	2·19	2·18	2·16	2·14	2·13	2·10	2·07	2·05	2·02	2·00	1·97	1·95
Bashams .	1·90	1·83	1·80	1·70	1·65	1·58	1·57	1·54	1·45	1·32	1·25	1·15	1·10	1·00	0·73

The barrage, where the preceding observations were taken, is about 16 miles below Rhoda, so a difference may be expected and will be found in the readings of the two nilometers.

The average heights of high Nile at Rhoda and at the barrage during a series of years are given below :—

Rhoda,[1]	6·97 mètres	= 22·86 feet	(average of	48	years,	1824–72)
Barrage,[2]	6·87 „	= 22·54 „	(„	16	„	1846–61)
Barrage,[3]	6·91 „	= 22·66 „	(„	10	„	1864–73)

The average heights in mètres at five-day intervals for the years 1846–61 have been tabulated by Lombardini as under :—

—	5	10	15	20	25	28 to 31
January	2·79	2·68	2·58	2·48	2·39	2·26
February	2·18	2·07	1·96	1·83	1·72	1·65
March	1·54	1·45	1·35	1·26	1·18	1·08
April	0·99	0·94	0·87	0·81	0·74	0·69
May	0·64	0·62	0·58	0·53	0·51	0·47
June	0·44	0·48	0·48	0·48	0·66	9·76
July	0·90	1·05	1·27	1·44	2·16	3·22
August	4·15	4·87	5·57	5·76	5·87	5·97
September . . .	6·09	6·13	6·18	6·17	6·19	6·48
October	6·60	6·55	6·51	6·37	6·21	6·22
November . . .	5·73	4·97	4·66	4·09	4·00	3·80
December	3·61	3·42	3·25	3·19	2·97	2·90

It will be understood that the above are the average heights in a series of years, and not the heights in an average year. If it had been the latter the maximum height would have been 6·87 instead of 6·60, and the minimum 0·30 instead of 0·44, the difference being due to the overlapping of the dates of maximum and minimum heights in different years.

The system of irrigation practised in upper Egypt appreciably affects the readings on the nilometers at Rhoda and at the barrage. When the Nile has attained a height of about 3 or 4 mètres, a large volume of water flows down the numerous canals having their beds at that height above low water; and when a still greater height is attained, banks are cut and the filling of the great basins of inundation causes the level of the water in the river to remain almost stationary for some days. In the same way, the drainage of these basins, after the water has stood on the land a sufficient period to deposit the fertilising matters in suspension, causes an abnormal rise in the river.

[1] "Statistique de l'Égypte." Cairo.
[2] Lombardini. "Saggio idrologico sul Nilo." Milan, 1865.
[3] Author's returns.

Four measurements of the ordinary low Nile discharge at the barrage by Mr. Fowler's engineers, and by General Stone's Egyptian staff, gave the following results:—

Cubic mètres per second.
Low Nile discharge = 355; 397; 415; 460; mean = 406 cubic mètres.
or, say, 14,000 cubic feet per second.

Three measurements at Cairo by Linant Bey indicate the following discharges for high Niles, ranging from 7 to 8 mètres in height above zero:—

Cubic mètres per second.
High Nile discharge = 8,166; 9,460; 9,740; mean = 9122 cubic mètres,
or, say, 320,000 cubic feet per second.

It has been shown that the maximum height of the Nile averages less than 7 mètres, so the average maximum discharge will also be less than the above. The Author, after consideration of all the data, estimates the latter at 8,400 cubic mètres, or say 296,000 cubic feet per second; and having reference to the preceding measurements at high and low Nile, and to measurements at intermediate levels by General Stone's staff and himself, he has deduced the following formula for the discharge of the Nile in cubic mètres per second, for any height h, in mètres above zero on the nilometer. As the Nile at low water is a series of pools at places, the local level of low water may vary with the same discharge, so the height h should be taken from the average readings on several nilometers.

$$Q = 200\,(h + 1)^{1 \cdot 8} + 150.$$

Applying this equation to the mean heights already given, the following will be the average discharge in cubic mètres per second throughout a series of years, at five-day intervals:—

Cubic Mètres per Second.

—	5	10	15	20	25	28 to 31
January	2,351	2,237	2,136	2,037	1,950	1,828
February	1,755	1,656	1,560	1,451	1,361	1,306
March	1,221	1,153	1,081	1,018	963	897
April	840	809	767	732	692	664
May	637	627	606	580	570	550
June	536	554	554	554	648	704
July	785	878	1,024	1,146	1,736	2,820
August	3,972	4,986	6,074	6,386	6,570	6,740
September	6,946	7,014	7,102	7,084	7,118	7,632
October	7,850	7,760	7,686	7,436	7,154	7,172
November	6,336	5,136	4,680	3,892	3,774	3,516
December	3,280	2,952	2,856	2,786	2,542	2,458

For an average year the minimum discharge will be 400 cubic mètres, and the maximum 8,400 cubic mètres, the difference, as already explained, being due to the varying dates of the maximum and minimum discharge in different years.

From the above tabular statement, and from the analyses of Nile water by Dr. Letheby and Professor Wanklyn, the Author estimates the discharge per month of water and solids to average as follows:—

—	Water in Millions of Cube Mètres.	Solids in Suspension in Tons Weight.	Solids in Solution in Tons Weight.
January . . .	5,616	942,000	815,000
February . . .	3,715	468,000	546,000
March	2,851	152,000	510,000
April	1,944	129,000	353,000
May	1,598	76,500	326,000
June	1,555	107,500	315,000
July	3,744	668,000	610,000
August . . .	15,508	23,100,000	2,570,000
September . .	18,532	10,100,000	3,600,000
October . . .	20,045	7,600,000	3,200,000
November . .	11,793	4,050,000	1,765,000
December . .	7,517	2,180,000	1,025,000

In an average year, therefore, the Nile conveys to the sea 49,573,000 tons of solids in suspension; 15,635,000 tons of solids in solution, and 94,418,000,000 cubic mètres, or, say, tons of water. Lombardini estimated the latter at 107,828,558,000 cubic mètres, but his data were imperfect.

The solids in the preceding estimate are of course assumed to be chemically dry, or the weight would be much greater. Thus, at the Cairo waterworks, it is found that at high Nile the solid matters deposited on the filters in the form of sludge are practically 800 parts per 100,000 of water, though Dr. Letheby's analysis indicates a maximum of 150 parts of chemically dry solids.

Large though these volumes be they would be exceeded if the measurements were taken higher up the river. Linant Bey measured the flow at Khartoum, where the White and Blue Nile join, and found the minimum and maximum flow for the year to be 297 cubic mètres, and 6,044 cubic mètres, in the instance of the former; and 159 cubic mètres, and 6,247 cubic mètres, in that of the latter. He measured also a high Nile discharge of 12,700 cubic mètres at Gibil Cilcilly, near the first Cataract.[1] No doubt

[1] "Travaux éxécuté en Égypt." Paris, 1873.

20 or 30 per cent. of the volume of the Nile is lost between Khartoum and the barrage by evaporation and absorption.

It was stated at the commencement of this Paper that by far the larger volume of water is conveyed to the sea by the Rosetta branch. This was not always so, but is a consequence of the construction of the barrage, and of the neglect of ordinary precautions in training the river immediately above that work. Unless matters are managed better in the future the river will take charge of affairs itself, and sweep the Rosetta half of the barrage down stream.

The Rosetta barrage is 1,525 feet in total length, and includes sixty-one arches of 16 feet 4 inches span each. The Damietta barrage is 1,787 feet long, and has ten more arches in the waterway. At low Nile, in 1874, about 200 cubic mètres per second flowed through the former, and 181 cubic mètres through the latter span. A few days later the volumes had increased to 305 and 268 cubic mètres, and the differences then rapidly grew wider.

In September 1877 the Author measured the flow down the two branches of the river, and the canals having their headworks at the barrage, as follows:—

	Cubic Mètres.	Mean Velocity of Current.
Rosetta branch . . .	3,220	3·28 miles an hour.
Damietta	1,830	1·56 " "
Menoufich canal . . .	230	
Behera " . . .	140	
Total . . .	5,420 cubic mètres per second.	

The high Nile of 1877 was one of the lowest and most disastrous for many years. At the time of the above measurement the nilometer above the barrage indicated a height of 5·25 mètres, and that below, 5·10 mètres. By the formula $Q = 200\,(h + 1)^{1\cdot 8} + 150$, the volume corresponding to the former height is 5,564 cubic mètres, and to the latter 5,332, the mean being 5,448, or practically the same as the measured amount.

The preceding figures, significant though they are, do not indicate the worst feature about the barrage works, namely, that the 1,830 cubic mètres do not approach the Damietta barrage fair and square, but are directed to it at great velocity through a narrow and deep channel at right angles to the axis of the river, and in line, therefore, with the already unstable foundations of the barrage. Thousands of tons of stone have been thrown into the cross channel, but the depth is still about 54 feet below low water, or 36 feet below the foundations of the barrage. Borings

to a depth of 100 feet show that the soil is light stuff which melts almost like sugar when in contact with water; so the present critical state of affairs requires no further demonstration.

The analysis of Nile water made for Mr. Fowler by Dr. Letheby is appended. (See next page.)

The late Dr. Letheby remarks with reference to the preceding analyses:—

"The amounts of solid matter dissolved in the water range from 13·614 to 20·471 parts per 100,000 of water. The former proportion was found in the December sample, and the latter in the sample taken in the month of May. It appears also that the quantity of dissolved matters gradually rises from December to June, after which, with the exception of the month of September, it as gradually falls.

"Looking at the individual constituents of the water, it will be remarked that the nitrogenous matters, as indicated by the amounts of actual and organic ammonia, as well as by the proportions of organic matter, are considerable; for in the former case the total quantity of ammonia (actual and organic) is from 0·0114 to 0·0271 part per 100,000 of water, and in the latter the organic matter is from 0·929 to 3·129 parts per 100,000 of water. These proportions are largely in excess of the quantities ordinarily found in the rivers of Europe.

"The salts of lime and magnesia which are present in sulphates and carbonates are not excessive, and therefore the water is well suited for domestic purposes.

"The proportions of soda in the form of chloride are also small; but those of potash, in the state of carbonate and silicate, are rather large. This is especially the case in the samples of water taken in June, September, and October, when the soluble constituents of the water have the highest fertilising power.

"It is, however, in the suspended matters that we are to look for the chief fertilising ingredients of Nile water; and these are most abundant in the samples collected in August and September. In the former case they amount to 149·157 parts per 100,000 of water, and in the latter to 54·257 parts. After this the proportions gradually fall to 4·772 parts, which was the quantity found in the water taken in the month of May of the present year.

"It appears also that the proportions of phosphoric acid and potassa, which are the chief mineral ingredients of agricultural value in the suspended matters of Nile water, are more abundant in the August and September samples than in those obtained at any other time of the year. This will be evident from the follow-

RESULTS OF ANALYSIS OF SAMPLES OF NILE WATER TAKEN DURING TWELVE CONSECUTIVE MONTHS.

Constituents per 100,000 parts.	1874.							1875.				
	June 8.	July 10.	August 12.	Sept. 20.	October 12.	Nov. 12.	Dec. 12.	Jan. 23.	Feb. 12.	March.	April.	May 13.
Actual or saline ammonia	0·0057	0·0129	0·0043	0·0100	0·0071	0·0064	0·0049	0·0087	0·0048	0·0036	0·0035	0·0014
Ammonia from organic matter . .	0·0114	0·0100	0·0071	0·0171	0·0143	0·0114	0·0108	0·0143	0·0166	0·0086	0·0107	0·0118
Dissolved matters: Lime	4·167	3·992	4·422	4·260	2·309	4·304	4·264	4·468	4·057	4·631	4·768	5·178
Magnesia . .	1·623	1·513	1·030	0·617	0·483	1·132	0·926	1·029	0·874	0·977	0·823	1·029
Soda	1·201	0·744	0·587	0·301	0·504	0·318	0·369	0·347	0·307	0·594	0·830	1·301
Potassa . . .	2·475	1·062	1·501	4·120	2·348	1·329	1·002	0·831	0·934	0·728	0·609	0·404
Chlorine . . .	1·643	0·831	0·628	0·209	0·491	0·207	0·276	0·242	0·251	0·613	0·916	1·737
Sulphuric acid .	2 808	2·838	1·837	1·996	1·908	1·911	1·764	1·960	1·813	2·263	2·009	2·931
Phosphoric acid	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace
Nitric acid . .	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace
Silica, &c. . .	0·701	0·713	1·129	1·257	1·843	0·986	0·814	0·857	0·729	1·271	0·714	0·671
Organic matter .	1·500	1·057	1·186	1·929	2·414	1·343	0·929	1·286	1·586	2·086	2·586	3·129
Carbonic acid and loss . .	4·182	3·616	4·281	4·754	3·557	3·427	3·270	3·451	4·120	4·651	4·936	4·091
Total on evaporation	20·300	16·386	16·601	19·443	15·857	14·957	13·614	14·471	14·671	17·814	18·186	20·471
Suspended Matters: Organic matter	0·829	9·114	18·414	5·914	4·586	3·686	1·943	1·914	1·086	0·686	0·514	0·943
Mineral matter	6·086	8·729	130·743	48·343	33·214	30·686	26·971	14·829	11·486	4·629	6·114	3·829
Total suspended .	6·915	17·843	149·157	54·257	37·800	34·372	28·914	16·743	12·572	5·315	6·628	4·772

ing Table, which shows the percentage composition of well dried Nile mud in the two periods referred to:—

PERCENTAGE COMPOSITION of the SEDIMENTARY MATTERS from NILE WATER.

	Samples taken in August and September.	Samples taken later in the Year.
Organic matters	15·02	10·37
Phosphoric acid	1·78	0·57
Lime	2·06	3·18
Magnesia	1·12	0·99
Potassa	1·82	1·06
Soda	0·91	0·62
Alumina and oxide of iron	20·92	23·55
Silica	55·09	58·22
Carbonic acid and loss	1·28	1·44
	100·00	100·00

"The conclusions from these results are:—

"1st. That the fertility of the Nile water is due to the organic matter, and to the salts of potash and phosphoric acid dissolved and suspended in it.

"2nd. That these constituents are most abundant in the water during the months of August, September, and October, when the river is in flood; and that it is during the period of inundation that the sedimentary matter, or mud, deposited from the water, is most valuable as a fertilising agent."

Professor Wanklyn read a Paper[1] on his analysis of the monthly samples of Nile water furnished him by the Author, and drew attention to the remarkable alteration in the proportion of chlorine, and the constancy of the hardness. His explanation of this is that storm water sweeps over the surface of a country without penetrating far into the ground, and as the surface has long been denuded of salt, very little chlorine is found in the Nile at flood. When the river has fallen, the water which has soaked into the soil drains back into the Nile, not only concentrated by evaporation, but charged with chlorine extracted from extensive strata; so it is no matter for surprise that the water at low Nile contains six to eight times as much chlorine as the flood water. The hardness is due chiefly to finely divided carbonate of lime, and the slight variation in hardness is due, according to Professor Wanklyn, to the varying amount of carbonic acid present in the river.

Well water is necessarily more heavily charged with salts than

[1] *See* "Water Analysis," 5th edition. London 1879

the Nile at the worst. This is clearly evidenced by the following abstract of the analyses of the water in some wells near Cairo, and in the river:—

	Well Water.	Nile Water.
Chlorine (per 100,000 parts)	7·28 to 25·4	0·21 to 1·74
Soda	5·13 „ 10·75	0·30 „ 1·30
Magnesia	2·81 „ 7·91	0·48 „ 1·62

Farther south, in the region of tropical rains, well water is still more impure. In 1876 Mr. Fowler, acting on the Khedive's instructions, sent an expedition, consisting of twelve engineers, one hundred and fifty soldiers, and four hundred camels, to explore the country between Aboo-Goosi on the Nile, and El Fascher in Darfour, and samples of water were brought from all the more important wells. In one of these, about 15 feet deep, situated at Mahtoul, 37 miles from the Nile, the quantity of common salt contained in the water was no less than 73 grains per gallon, and in few others was it less than 50 grains.

Observations of the fluctuations in the level of the water in Egyptian wells afford interesting data with respect to the rate of filtration through fine sand. In 1867–68 daily records were kept of the varying level of the water in the Nile at Assouan and at Cairo, and in a well situated 1½ mile from the river at the latter place. The following Table shows the height of water in the Nile, and in the well at Cairo, in mètres above the low Nile of 1867, at intervals of ten days:—

—	10th.		20th.		28th to 31st.	
	Nile.	Well.	Nile.	Well.	Nile.	Well.
January	2·03	2·35	1·86	2·20	1·70	2·05
February	1·55	1·92	1·45	1·76	1·35	1·65
March	1·18	1·47	0·81	1·36	0·69	1·30
April	0·62	1·18	0·56	1·05	0·45	0·87
May	0·40	0·68	0·28	0·57	0·14	0·42
June	0·05	0·27	0·00	0·08	0·50	0·05
July	0·75	0·00	1·13	0·10	2·06	0·28
August	3·63	0·35	4·60	0·69	5·55	1·25
September . . .	5·97	1·98	5·73	2·32	5·72	2·69
October	5·37	2·91	5·27	3·21	6·09	3·47
November . . .	4·68	3·66	3·75	3·45	3·09	3·21
December . . .	2·54	3·02	2·40	2·80	2·18	2·56

Between July 11th and November 8th the water in the well was rising, and for the remainder of the year it was falling. In a certain sense, therefore, it may be said that the water flowed into the well from the river for four months, and into the river from the well for eight months.

At Assouan, 573 miles above Cairo, the rise commenced on June 6th, or about a fortnight earlier than at Cairo; and the maximum flood was 8·03 mètres, as compared with 6·09 mètres at Cairo.

(*Paper No. 1708.*)

"Rack Railway worked by Endless Ropes, for Steep Inclines."

By Tommaso Agudio.

(Translated and abstracted by Alfred Bache, B.A., Assoc. Inst. C.E.)

The plan invented by the Author is intended for railways in mountainous districts, for working inclines of 1 in 10, or even steeper, and with curves as sharp as 500 feet radius. This is accomplished by a central rack-rail, and a propelling car or "locomotor," fitted with horizontal driving pinions gearing into each side of the double-faced rack. The ample water-power available in such localities is utilised through turbines driving a pair of endless ropes, by which the driving power is communicated to the locomotor.

The turbines, situated conveniently near the foot of the incline, are geared to a pair of main grooved driving pulleys; whence each of the endless driving ropes, after passing round a tightening sheave loaded by a weight, is led up the incline, one on each side of the line, supported at suitable intervals on carrying sheaves, with inclined guide-sheaves round the curves. In its course each rope passes also round a pair of large vertical driving pulleys on each side of the locomotor, which drive through friction clutches and mitre wheels the two pairs of horizontal pinions gearing into the rack-rail. At the top of the incline the ropes pass round vertical guide-sheaves; and thence return to the foot of the incline by any shorter and more direct cut that is practicable, instead of following the windings of the railway. These endless ropes are accordingly employed, not as ordinarily for direct haulage of the train on the incline, whereby the full strain of the load would be thrown wholly upon them; but as quick-running driving ropes, for communicating the driving power from the turbines to the propelling mechanism of the locomotor, whereby the strain on the ropes is reduced below that of the load, in proportion as their speed is higher than that of the train. In ascending, the train is pushed up from behind by the locomotor in the rear, and in descending is held in check by it in the front. The locomotor being always at the lower end of the train on the incline, all risk of accident through breakage of drawbars is obviated.

This plan was first tested experimentally in 1862, on the old Dusino incline of the Turin and Alessandria railway—a portion of the line which had been abandoned, owing to the steepness of the gradient, the sharpness of the curves, and the bad ground. The ropes were here driven by steam power; and trials in comparison with coupled locomotives of special construction showed a superiority of 50 per cent. and upwards in favour of the Agudio system. The report in 1864 of the late M. Charles Couche, one of the French commission appointed to investigate the Dusino experiments, was highly favourable to the plan, and he recommended it as deserving of the utmost encouragement from the French government, as it presented such important and indisputable practical advantages over locomotive working, and formed a novel and efficacious expedient for speedily and cheaply surmounting the natural obstacles encountered in mountainous districts.[1]

Upon the further recommendation of M. Couche, a practical trial of the plan on a larger scale was authorised in 1868. The site selected was on the French slope of Mont Cenis, where the construction was commenced of an incline of excessive steepness, rising from the valley of the Arc, near Lanslebourg, to nearly the summit of the ridge. The works were interrupted during the Franco-German war, but were resumed in 1872; and the incline was opened for working in 1874, having a length of 1463 yards, or 0·83 mile, and a rise of 1150 feet, from 4730 to 5880 feet above sea-level. The average gradient was thus 1 in 3·82, or 26 per cent., the steepest part being 1 in 3·14, or 31·8 per cent. The incline was laid with a single line of rails, of the ordinary 4 feet 8½ inches gauge, with the rack fixed midway between them.

The rack was made in 2-feet lengths, out of a single flat bar of steel, of 4⅜ inches × ½ inch section and 6 feet in length, which was crimped or corrugated transversely while hot in accurately shaped dies under a hydraulic press, so as to form a double rack of 4 inches pitch, and 4⅜ inches width and height. It was placed on edge, so that the rack teeth facing towards either side were the spaces facing towards the other. These 2-feet lengths were riveted up in sets of three, between top and bottom bars of shallow channel-iron, each 4⅜ inches wide by $\frac{5}{16}$ inch thick; and the 6-feet lengths thus formed were strongly bolted down upon a centre longitudinal sleeper. The rack was made at the works of Messrs. Brunon, Rive-

[1] *Vide* also Articles 455–469 in M. Couche's work on Railways, "Voie, materiel roulant, et exploitation technique des chemins de fer." 3 vols. 8vo. Paris, 1867–76.

de-Gier, France; its construction elicited high approbation, and is seen to be much superior in point of safety to the Rigi rack, which is nothing else than a ladder.

The pair of turbines at the foot of the incline were 6 feet in diameter, with 450 feet head of water, and a combined nominal power of 900 HP. They ran usually at two hundred and fifty revolutions per minute, and were geared 5 to 1 to the main driving pulleys of 13 feet in diameter, giving a speed of 34 feet per second, or 23 miles per hour, to the ropes. These were $\frac{7}{8}$ inch in diameter, of steel wire with hemp core, and weighed 3 lbs. per yard. The strain upon each rope in working never exceeded 2 tons total, or 8 tons per square inch of metallic section. The direction of running was upwards along the incline. The driving power was communicated by their simple adhesion in the grooves of the main driving pulleys and of the locomotor pulleys. The locomotor travelled at one-fifth the speed of the ropes, ascending the incline therefore at nearly 7 feet per second, or 5 miles an hour. The pulleys were put in gear with the horizontal driving pinions through friction clutches, for starting the locomotor gradually. With the four pinions working into the rack-rail there were always four teeth in gear, dividing the propelling thrust among them, instead of the whole thrust coming upon a single tooth of a rack having only one pinion gearing into it. The plain rims of the pinions bore against the flanges of the channel-iron bar forming the top of the rack-rail, and thus steadied the locomotor laterally, in conjunction with the flanges on the four carrying wheels. During the ascent four safety-pawls, or catches, clicked into the rack-rail, for scotching the locomotor instantly in the event of accident.

The descent being made by gravity alone, the ropes remained stationary; and the speed was controlled by three powerful brakes upon each locomotor, of which there were two. The first brake applied on starting to descend, and kept on throughout the descent, was a long skid or slipper brake, gripping tightly between its strong jaws the longitudinal sleeper of the rack-rail; the sides of the sleeper were faced with plain iron bars for the skid to slide against. If more brake power was required, a pair of wood brake-blocks were applied, in one of the locomotors, against a drum on the shaft of each horizontal driving pinion. In the other, a hydraulic brake was employed, somewhat on the dash-pot principle: each pinion-shaft was cranked, and worked a piston in a water cylinder, with a passage communicating from one end of the cylinder to the other; by throttling this passage to half the area, a

powerful resistance was opposed to the rotation of the pinions gearing into the rack-rail. A third resource for retarding the descent was supplied in each locomotor by a pair of vice-plates, between which the rims of the rope-pulleys were gripped laterally, for bringing into play the brake action available from the slipping of the ropes round the pulleys. The second source of brake power was employed sparingly and with great caution, to avoid straining the driving gear; while with the third this was still more stringently the case, to avoid wear of the ropes.

Towards the end of the year 1875, elaborate experiments on the working of the Lanslebourg incline were conducted for more than three months by a commission of the Italian[1] and French governments and of the Eastern Railway of France.[2] During that period the ascent of the 1150 feet rise was regularly performed with heavy loads at a speed of about 5 miles an hour; and the trains were stopped and started at pleasure at any point upon the incline with the utmost readiness and without the slightest jerk. By means of a Prony friction-brake upon the shaft of the rope-driving pulleys at the turbines, it was ascertained that the power required for driving the pair of ropes alone, when running empty, amounted to 100 HP.; the locomotor, weighing 12 tons, took $239 - 100 = 139$ HP.; and a train of 24 tons, exclusive of the locomotor, required $438 - 239 = 199$ HP. The useful effect was therefore $\frac{199}{438} = 45$ per cent.; which seemed to the Italian commissioners so much higher than likely, that they reduced it to 38 per cent. by calculating the several resistances of the train from the data furnished by the regular working of ordinary railways.

In a letter addressed last year by Signor Agudio to the Italian parliament,[3] he points out that, even taking the lower figure of 38 per cent. for the above useful effect, this would be equivalent to at least 50 per cent. on an incline of only 1 in 10, less power being then absorbed in raising the dead weight of the locomotor itself. Moreover the old large wagons, out of use, that were lent for the experimental trains, had a wheel-base of no less than

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[1] Sul Piano Inclinato di Lanslebourg a Trazione Funicolaresecondo Il sistema dell' Ingegnere Tommaso Agudio. Roma, 1876. (This contains an elaborate detailed description of the entire plant and working, with particulars of the whole series of experiments; it is illustrated by thirteen plates.)

[2] Rapport des Délégués de la compagnie du Chemin de fer de l'Est sur le Plan Incliné de Lanslebourg: Paris, 28 December 1875. (Four plates.)

[3] Il Sistema Agudio per vincere le Forti Pendenze coi Treni Ordinari delle Ferrovie. 8vo.: Roma, 1879.

11·8 feet, which was ill suited to curves of only 500 feet radius; hence the coefficient of tractive resistance adopted by the commissioners, of only 0·00386, or 8·6 lbs. per ton of load, is far too low; and upon half the length of the incline the resistance must have amounted to ten times as much. For the cheaper construction too of the incline, second-hand timber, much damaged, had been procured from the previous Fell railway in that locality; the consequent want of steadiness in the structure, together with the lateral oscillations of the train, contributed to increased friction between the driving pinions and the rack-rail. The commissioners' calculations again were based on their earliest experiments, in which the weight of the whole train did not exceed 36 tons, including the locomotor, and the speed was only 6½ feet per second, or 4½ miles an hour; while later on, ten journeys a day were performed with trains of 45 tons total, at a uniform speed of 7½ feet per second, or 5⅛ miles an hour, both in ascending and in descending. On all accounts therefore the Author considers it would be fairer, while still safely within the mark, to take 52 per cent. as the useful effect on the incline of 1 in 3·82; which corresponds to 63 per cent. on an incline of only 1 in 10.

The commissioners from the Eastern Railway of France included in their report an estimate of the superiority of the Agudio system over their own most powerful locomotives with eight coupled wheels, working up the steepest gradient practicable, say 1 in 40. The useful effect of those engines is calculated from their coal consumption at 20 per cent. as a maximum; while that of the Agudio system, calculated from its water consumption, is $38 \times 0 \cdot 80 = 30$ per cent. as a minimum, the turbines utilising 80 per cent. of the water-power expended. An equal expenditure of power would convey 1·8 time as much load up the rack incline as up the locomotive gradient, while the capital outlay on works and plant would be only one quarter as great: hence the Agudio system is estimated to be altogether 7·2 times the more economical.

The advantages of this system for an incline of 1 in 10 are summed up by the Author as follows:—

1. Nearly twice as much traffic can be worked in a given time as by locomotives.

2. The capital outlay required is little more than one-third. (The French estimate just quoted of only one-quarter was for the steeper gradient of 1 in 3·82.)

3. No inconvenience or delay is occasioned to the working of the regular trains; on the contrary they would be conveyed up an equal height in little more than half the time and with greater safety.

4. The working expenses are greatly reduced, as the incline of 1 in 10 is only a quarter the length of a locomotive gradient of 1 in 40, and the use of water-power saves all consumption of fuel.

5. Steeper mountain slopes can be ascended, and the summit tunnel through the ridge can thus be considerably shortened, or even done away with altogether under favourable conditions of climate and ground.

In a further letter[1] to the Italian Minister of Public Works, Signor Agudio disposes of the objections to the adoption of his system in connection with ordinary lines of railway. He explains in detail the mode of working trains at the junction stations at the top and bottom of the incline, the propelling car there taking its place at the lower end of the train, while the locomotive shunts off into a siding. The rack-rail, standing its own height above the ordinary rails, is made with a tongue to open, like an ordinary switch, where it crosses the main-line rail at the junction; while the rope there drops into a narrow slot crossing each of the main-line rails obliquely. The propelling car is enabled to run backwards as readily as forwards on the level landings at the top and bottom of the incline, by providing it with an ordinary reversing clutch in the driving gear, the ropes continuing to run always in the same direction, upwards along the incline. For working regularly trains of 180 tons useful load, a steel-wire rope weighing 3 lbs. per yard, and running at the same speed as at Lanslebourg, would suffice for a rise of about 2300 feet, which would give nearly 4½ miles length for an incline of 1 in 10. Without any reduction of load, a slight increase in the size of the rope or in the speed of running would allow of the incline being extended to 6 miles, giving a rise of 3000 feet. The system thus lends itself with great readiness to the various requirements of railway routes. As the ropes do not act by direct haulage, but drive by simple adhesion in the groove of the locomotor pulleys and through a friction clutch, any sudden increase of train resistance throws no severe strain upon the ropes, but merely causes them momentarily to slip on the pulleys at the first instant; and the slipping then transfers itself immediately to the friction clutch, which is adjusted beforehand to slip whenever the pull upon the ropes rises only 10 per cent. above their normal tension in regular working. Repeated experiments equivalent to actual breakage of the ropes at Lanslebourg showed that the ascending trains were instantly scotched dead at any point on the incline, by the four catches

[1] L'Innesto del Sistema Agudio alle Ferrovie Ordinarie. 8vo.: Torino, 1879.

clicking into the rack-rail, without any occasion to apply the brakes. Failure of one of the pair of ropes would not delay passenger trains, which could be worked by the other rope singly while the broken rope was being spliced.

Signor Agudio urges the adoption of his system for the ascent of Tivoli, about 16 miles from Rome, on the projected Rome Aquila and Solmona railway, where a short cut can be made by a rack-rail incline of only 1¼ mile length, with a ruling gradient of 1 in 10 and curves not sharper than 1,000 feet radius, in place of a loop five and a half times as long, which would be required for the proposed locomotive gradient of 1 in 70, the total rise being 500 feet. The cost of the work is estimated at about £20,000 for the entire construction of the incline, laid with a single line of rails of 4 feet 8½ inches gauge, with the rack-rail between them; £2,400 for two pairs of steel-wire ropes weighing 3 lbs. per yard, one pair to be kept in reserve; £8,400 for driving pulleys, tightening, guiding, and carrying sheaves, &c., with a sufficient supply of duplicates in reserve; £5,000 for three 12-ton locomotors; and £10,000 for the hydraulic power, including two pairs of turbines of 1,000 HP. in the aggregate, one pair to be in reserve for emergencies. Adding for contingencies and superintendence &c., the total estimate amounts roundly to about £56,000. Trains of 180 tons would make the ascent or descent of the incline in ten minutes. By the adoption of similar inclines at other points on the same difficult line of railway of 100 miles in length, 30 miles might easily be saved out of the heavier portions of the works, and shorter tunnels would suffice.

(*Paper No. 1709.*)

"Dredging Operations on the Danube, between Pressburg and Gönyö in Hungary."

By Murray Jackson, of Pesth.

The navigation of the Danube in Hungary, more especially that portion of it between Pressburg and Gönyö, is greatly impeded by the constantly-changing formation of shingle banks, which, although during the season when the water is high are sufficiently covered to allow the passage of laden vessels, in summer and autumn, when the water is usually low, are at times partially exposed, or only covered to a depth of 3 to 3½ feet. A correction of the river in this portion of its course has not yet been attempted, and it is thus suffered to spread itself over a great width, studded with numerous islands. As a consequence the navigable channel of one year deviates considerably from that of the previous one. The average current on those parts of the river where the shallows occur is 4½ to 5 miles per hour. It has hitherto been customary to dredge the shallow parts which form for the time being the hindrance to the passage of laden barges, but the channels being narrow, the presence of the dredger necessarily becomes a hindrance to free navigation. It has also been customary to discharge a portion of the cargo of a laden barge on arriving at such points, thereby reducing the draft from 5 or 5½ feet (which is the maximum) to 3 or 3½ feet. In addition to the expense of reloading, the large number of barges thus rendered necessary for the traffic is inconvenient, and considerable delays ensue. These difficulties and hindrances caused the Danube Steam Navigation Company to try a system of deepening the river (Plate 17) which, so far as may be judged from the short time it has been at work, appears to be successful. It may be stated that the bars or banks formed in the bed of the river consist almost entirely of rolling shingle, varying in size, and rounded by the action of the water. These stones, brought down by the Inn and other tributaries from the mountains and worn quite smooth, are formed by the sand of the river into compact masses, having sufficient adherence on their surface to hold very firmly together, but which, if once loosened, would be carried away by the current, and de-

posited in deeper water at some point lower down the river. The loosening of the upper surface of such shingle-beds is effected by the implement shown in Plate 17. This "rake" is of a triangular form, and is suspended from the bows of a steamer, being hung, however, somewhat in advance of the same. The chain by which the rake is suspended passes over a pulley inserted in the end of a strong beam of timber A, and serves to lower or raise the whole by a steam crane placed on the forward deck. The shingle banks forming the obstructions described are seldom more than 100 to 200 yards in length, and the steamer beginning at the upper end, ploughs through them, running astern, and dragging the rake by chains attached to suitable towing bits at the bows. After passing over the shingle and reaching deeper water the rake is raised by the steam winch, and the engines are reversed, the steamer ascending the stream to the head of the bank, and taking up a position to make a fresh descent, for which purpose the rake is lowered and the process repeated. This plan, the success of which in a great measure depends upon the power of the stream to disperse and carry away the loosened shingle, is said to have been tried many years ago, when, however, a very light rake was towed from the stern of the steamer, which ran down the stream dragging the rake after her. The great difficulty, however, encountered then in steering rendered its application uncertain, and it was not continued. This difficulty has been entirely overcome by dragging the rake from the bows, the steamer running astern, and thus leaving the action of the rudder undisturbed. In five days during November 1879 the rake passed three hundred and fifty-five times over a shingle bank, the depth upon which was increased from 5 feet 6 inches to 9 feet. The current in this part being sluggish, the rake had to pass oftener. The barges employed by the Danube Company are mostly 180 feet long by 21 feet beam, and carry 250 tons on a draft of 5 feet; they are built of iron, and on account of the strong currents encountered have usually rather fine water-lines. No difficulty has hitherto been experienced from the loosened shingle being deposited lower down the stream, and as by the means described a sufficient depth of water can be gained in a short time, the system, although a rough and ready one, possesses considerable advantages. The frame of the rake is of wrought iron, and weighs complete $3\frac{3}{4}$ tons, measuring on each of its three sides 18 feet. It is provided with thirty-four teeth of chilled cast iron, projecting 12 inches from the underside; these teeth bite by the weight, and pull on the chains to rather more than half their depth. The engines of the steamer employed indi-

ANUBE.

PLATE . 17

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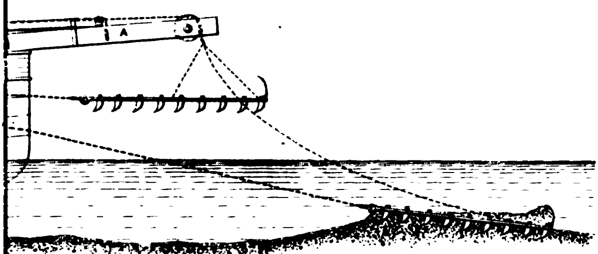

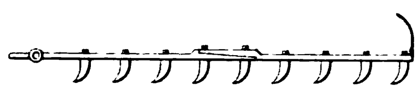

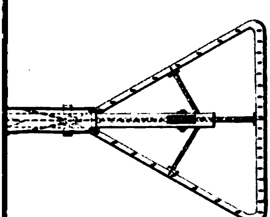

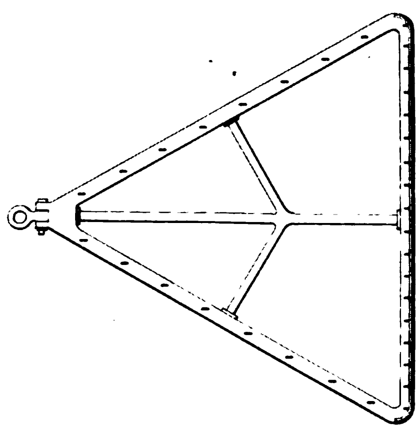

Scale ¼ Inch = 1 Foot

THOS KELL & SON LITH 40 KING ST COV. GARN

cate, when working full power, 440-HP. An experiment, in which the steamer was made fast by hawsers, showed that the engines when dragging the rake would be capable of exerting a pull equal to $4\frac{3}{4}$ tons. The engines are oscillating, with cylinders $41\frac{1}{2}$ inches in diameter and 3 feet stroke; the pressure of steam is 30 lbs. It may be added that this steamer was selected for carrying the rake on account of her light draft of water, only 2 feet 6 inches. When the water is high and there are no hindrances to be overcome, the apparatus is dismounted until again required.

The communication is accompanied by a tracing, from which Plate 17 has been engraved.

MEMOIRS OF DECEASED MEMBERS.

Mr. ALFRED WINGATE CRAVEN, the second son of Mr. Tunis Craven, was born on the 20th of October, 1810, at the Washington Navy Yard, D.C., during the time his grandfather, Commodore Tingey, was in command of that station. Two of his brothers entered the naval service; one, Captain T. A. M. Craven, went down in the "Tecumseh," at the battle of Mobile Bay, in the civil war; the other is the present Admiral T. T. Craven, U.S.N. The grandfather having been removed to the naval station at Portsmouth, Alfred was sent to school at Exeter, N.H., and at Berwick, Me., whence he went to Yale College, and afterwards to Columbia College, where he graduated in 1829. He then studied law, and was admitted to the bar; but not being fascinated with the confinement of a lawyer's office, he left the law to become a civil engineer. At that time, 1835, railroads were just being commenced; few men had any practical experience in this branch of engineering, none scientific training. Mr. Craven possessed a fine *physique*, and was practised in all manly exercises, so that he readily accepted the change of occupation. His first work was in connection with the surveys and construction of the Mad River railroad, on which he served as an assistant engineer. At the end of his initiatory year, he joined a large and dashing corps of young engineers, fitted out by General McNeil, formerly of the U.S. Engineers, to survey, locate, and construct the first division of the Louisville, Cincinnati, and Charleston railroad, in South Carolina, upon which work he was engaged for three years, and where he won many friends by his industry and marked character. Then he accepted a prominent position under Major Whistler, also formerly of the U.S. Engineers, on the Boston and Albany railroad. Next he was employed on the central division of the Erie railroad, as chief assistant, until that work was suspended in 1842. Subsequently he had charge, on the Mohawk and Hudson railroad, of a change in the line and of the running of the inclined planes; but not liking the manner of the President, he transferred his services to the Reading railroad, and constructed the coal basins, piers, and wharves on the Delaware river. Afterwards he became the Engineer-in-chief of the Schuylkill Valley railroad, and soon added to these duties a similar position on the Mine Hill Naviga-

tion railroad, both lines being completed under his direction. Finding that the health of his family required a change, he went south, and took charge of the building of the Camden branch railroad in South Carolina. When this work was finished, after refusing to construct the Columbia and Charlotte railroad, he returned to the city of New York, and, through the assistance of many influential friends, he was, in July 1849, appointed Chief Engineer and Commissioner of the Croton Aqueduct department, a position which he occupied for nineteen years, with great credit to himself and great advantage to the property holders of the city. His experience had hitherto been almost entirely confined to railroad construction; but he had been distinguished for executive ability, and for fearless and uncompromising honesty, which were essential requisites for his new position. He was frequently abused and accused; but in every instance he came out of these attacks purer and stronger than ever. Courageous as a Bayard in his ways and manner, he might have had given to him the same motto: "sans peur et sans reproche." He once said to a friend: "I can fight the whole body of vagabonds single-handed, without fear and without favour from any one, and I feel that I can whip them every time." He had a good knowledge of human character, and soon surrounded himself with clever and efficient assistants, who became firm friends; and this spirit extended to all the employés on the works, who knew that he would be as just to them as he was to the city treasury. During his administration as engineer of the Croton Aqueduct, the growth of the city required extensive additions to the waterworks. The distribution of water was greatly increased, the large receiving reservoir in the Central Park was built, as well as those on Blackwell's and Ward's islands, which were connected with the city services by pipes laid under the bed of the river. A complete survey was made of the watershed of the Croton river, and the large catch-basin at Boyd's Corner was commenced, together with the pumping-engine works, and the reservoir tower for the high service; also a wrought-iron main pipe, 7½ feet in diameter, was carried over the High Bridge, above the previous pipe, and was brought into use without interrupting the flow of water into the city for a single day. The sewer department was incorporated with the Croton Aqueduct department, and, under Mr. Craven's supervision, the present system of sewers was projected, and many miles completed, before he resigned office on the 12th of May, 1868, which he did to the regret of the entire community, for he was known and esteemed as one of the most upright, faithful, and careful

public officers the city ever had. He then, with his family, made an extensive tour in Europe, spending one summer in Sweden, studying the canals and river communications, and met with a most gracious reception from the King, from whom he received many favours. In Egypt Count Ferdinand de Lesseps paid him marked attention, and he was the first to carry the American flag through the Suez Canal. On returning to the United States he opened an office in New York. During his connection with the Croton Aqueduct department he had been frequently called upon for advice by the engineers of other waterworks; this he always gave with promptness and great cheerfulness, for it was a pleasure to him to assist the younger members of the profession. He was, as Engineer-in-Chief, or as Consulting Engineer, connected with many waterworks, as those at Brooklyn, Savannah, and Augusta; and he was directly or indirectly connected with most of the works, projected or constructed, for the supply of water to many towns, his reputation in this branch of engineering having been more extensive than that of any other person in America. He was now again called into consultation on the construction of the Hempstead reservoir in Brooklyn, on the Syracuse waterworks, and on the supply of water for the city of Newark, the Gilbert elevated railroad, the Quarantine Hospital, the Fire Department, the Rifle Range, the Yacht Club, and many other institutions of the city of New York, and was appointed one of the Commissioners of the Fourth Avenue improvements. Failing in health, he went again to Europe in April 1878, but his disease was irremediable, and he died at Chiswick, near London, on the 27th of March, 1879. His remains were conveyed to New York, where they were interred with all the honours paid to public men in that country.

No engineer has had in America a more extended reputation and no one has contributed more to give character and standing to the profession in that country. He was one of the first to assist in forming an American Society of Civil Engineers, of which he was elected a Member on the 1st of December, 1852. On the 29th of January, 1858, he read a Paper before that body, entitled, "Description of a line of large Water Mains laid by the Croton Aqueduct Department of the City of New York; and an inquiry into the causes of failure of a few of them." On the re-organization of the Society in 1868 he became one of its directors, and was its President during the years 1870–71. His idea of duty to the profession and to his employers was high; honest in his convictions, he was bold in expressing them, and never avoided official or personal responsibility. His friends were many; his enemies few, if any.

Mr. Craven was elected a Member of The Institution of Civil Engineers on the 1st of February, 1870. During his visits to Europe he was remarkable for the great number and high character of the friendships he formed. His chivalrous bearing, his extensive and thorough knowledge, and his extraordinary social gifts, secured a welcome wherever he travelled. He was on terms of intimate friendship with several well known English engineers, to whom his singular power of exposition in discussing professional details was no slight additional attraction to the other charms of his society.

Mr. JOHN GEORGE COCKBURN CURTIS, who some years since took in addition the name of Godsman, was born on the 6th of April, 1817. When five years old he accompanied his father, an officer in the Royal Navy, on a voyage to India. He remained about two years at Madras, where the basis of his education was laid, and then returned to England. After a brief interval he was admitted into the Royal Naval School at Greenwich, at that time presided over by Dr. Riddell. Here, on one occasion, some mathematical formulæ, roughly sketched out by the boy, attracted Dr. Riddell's notice, by the originality of thought indicated in their treatment, and from this date Dr. Riddell took kindly to the youth, and fostered his growing talents.

On leaving the Greenwich school, at the age of thirteen, he entered the Royal Navy as a volunteer of the first class, and sailed to the Mauritius, returning in about three years. During the space of a year and a half spent at home he prepared a set of tables of lunar distances (published by Messrs. Weale) which came under the observation of Professor Airy, who reviewed them favourably. This production obtained him an appointment, at the age of seventeen, to H.M.S. "Sulphur," as midshipman, and the principal part of the ten and a half subsequent years was spent at sea, in acquiring a thorough knowledge of seamanship. He made repeated voyages to China, India, and the Pacific, under, among others, Captains Beecher and Belcher. Under their guidance he became an accomplished sailor, imbued with large and manly views of duty and discipline. His avocation afforded ample opportunities for the study of hydrography, marine and river surveying, the improvement of harbours, and the construction of lighthouses, branches of engineering to which, in after life, he chiefly devoted himself, and in which his reputation stood deservedly high.

Mr. Curtis having decided upon quitting the Royal Navy,

next entered into the service of the East India Company, on the navigation works executed under the orders of Sir Arthur Cotton in the Cauvery and Coleroon rivers. Upon his return to England, at the age of twenty-seven, he was, in conjunction with Captain Wolfe and Lieut. Beechy, directed by the Admiralty to make a survey of the cove of Cork. Upon the completion of this survey he entered the hydrographer's office, where he executed many drawings of great fidelity. In 1845 he was selected by the Admiralty for the discharge of important duties in connection with the "Tidal Harbours Commission." During the performance of these services he became intimately acquainted with the peculiarities of the rivers Mersey and Nene, and subsequently took an influential part in countenancing judicious and in discouraging injudicious proposals for their treatment. From 1846 to 1849 he was employed by the local authorities as well as by the Admiralty to conduct minute investigations into the tidal phenomena of those rivers, and of the Dee, and to report upon the effect of projected works in relation thereto. For these purposes he carried out exhaustive surveys of all the physical features of the respective districts, including a project for the navigation for sea-borne vessels from the port of Great Yarmouth to the city of Norwich. In May 1849 he surveyed the lower portion of the river Nene, in connection with the Admiralty inquiry into the Norfolk Estuary Bill of that year. In April 1850 he made an elaborate report to the Admiralty on the proposed Hartlepool West Harbour and Docks.

In 1852 he was at New York, engaged in the Croton Aqueduct department. On leaving the United States he went to Spain, where for a considerable period he worked under the Spanish Government in the irrigation of the "Patrimonia Reale." On the conclusion of this engagement he returned to England, and in March 1859, was commissioned by the Admiralty to inspect the works of the Isle of Wight Ferry Company, and to hear evidence thereon. In 1861 he was required to report upon Durand's patent for an improvement in the manufacture of chain cables. In the latter half of this year he was again engaged in surveying the river Mersey, at and near Runcorn Gap, in order to show the state of the Channel where it was intended to be crossed by the London and North Western railway. In March 1862, Mr. Curtis, as Admiralty Inspector, again held an inquiry on the proposed Nene Valley Drainage and Navigation Works. In 1864 he went to Turkey, and was employed on the Smyrna and Casaba Railway. In 1865 his services were retained on behalf of the

Duke of Bedford, in making surveys of the river Nene below Peterborough Bridge.

The last record of his public labours was in June 1868, when he was requested to report on the proper utilization of the fresh-water supply to the Thorny river, a tributary of the Nene. But it is known that he spent the succeeding nine years in unremitting activity of mind and body, frequently making long and toilsome journeys in England and on the Continent in pursuit of scientific and general knowledge—travelling on foot over the greater part of France and Spain. In 1877 he had a slight attack of paralysis, from which he quickly recovered. In 1878 he again went to the United States, where he visited Florida, and in the following year he returned to England. But, by this time, his naturally vigorous constitution had begun to suffer from the effects of over-toil, in early life, in India, though his mental powers remained unimpaired to the last. On the 4th of December, 1879, he was stricken with apoplexy in Westminster, and died on the following day.

Mr. Curtis was elected an Associate of the Institution of Civil Engineers on the 6th February, 1844, and was transferred to the class of Member on the 12th of December, 1865. Whenever his avocations permitted, he was an assiduous attendant at the meetings, taking great interest in the proceedings, and not unfrequently joining in the discussions. His talents were exceptionally high, and his character for honour and integrity was indisputable. He practised the greatest self-denial, was ever anxious to do full justice to other men's merits, and in no instance did he withhold a due share of credit to those who assisted him in his labours. He possessed considerable literary powers, and was attached to the study of philology and social science. These tastes furnished occupation for his few leisure hours; but, as he was ever ready to sympathise with his suffering fellow-creatures, the greater part of his time, when not professionally engaged, was spent in strenuous efforts for the amelioration of the condition of those who were in a humble walk of life; giving up all, even the most innocent luxuries to relieve the wants of the poor and needy.

MR. WILLIAM FROUDE, LL.D., F.R.S., the fourth son of the Ven. R. H. Froude, Archdeacon of Totnes, was born at Dartington Parsonage, on the 28th of November, 1810. He was educated at Westminster School, and went thence to Oriel College, Oxford, being for some time a pupil of his elder brother, R. Hurrell Froude,

an advantage to which he often referred. He took a first class in Mathematical Honours in 1832.

In the beginning of the year 1833, he became a pupil of Mr. Henry Robinson Palmer, V.P. Inst. C.E., then Resident Engineer of the London Docks. Mr. Froude was afterwards employed under Mr. Palmer on some of the early surveys for the South Eastern Railway and on other undertakings.

In 1837, Mr. Froude joined the engineering staff of Mr. Brunel, V.P. Inst. C.E., upon the Bristol and Exeter railway, where he had charge of the construction of the line between the Whitehall Tunnel and Exeter, and remained until it was opened in May, 1844. Here was evinced that painstaking attention to detail which ensured the truth of his later work. As one of many instances it may be mentioned that, in two elliptical brickwork skew-bridges, he introduced taper bricks so arranged as to make correct spiral courses. It was while employed on this line that Mr. Froude propounded the "curve of adjustment," many years afterwards described by him in a Paper read and discussed before the "Institution of Engineers in Scotland," on the 28th of November, 1860, and on the 23rd of January, 1861. In the autumn of 1844, he was engaged on the Parliamentary surveys of the Wilts Somerset, and Weymouth railway, but shortly afterwards he gave up the active pursuit of the profession in order to live at Dartington with his father, who was then in failing health.

As one of Mr. Brunel's most intimate friends, Mr. Froude had still many opportunities of being associated with important engineering work. The progress of railways in Devonshire, and the trial and failure of the Atmospheric System, were subjects which Mr. Froude studied carefully.[1] A noteworthy instance in which Mr. Froude gave valuable help to Mr. Brunel was at the launch of the "Great Eastern" steamship, in 1857. The friction of the iron sliding surfaces had been tested by means of an experimental cradle, loaded so as to represent a portion of the actual cradle. To this experimental cradle Mr. Froude fitted a simple self-recording apparatus. He made a powerful pendulum, of very short period of vibration, by hanging a piece of double-headed rail lengthways on centres. A paint brush attached to this pendulum marked every quarter-second of time on a tape attached to the moving cradle, thus furnishing a record of motion, from which the exact amount of the retarding force of friction could be determined for each

[1] The description of the trial of the atmospheric system, in the published life of Mr. Brunel, was written by Mr. Froude.

moment of the motion. Mr. Froude's experiments showed conclusively, that the friction was not, as stated in text-books, independent of the velocity, but that it became much less as the velocity increased. The same recording apparatus was applied to the movements of the ship while being launched, and similar phenomena were observed. During the discussion of this question at the launch of the "Great Eastern," Mr. Froude pointed out how the fact of friction varying with the speed of the surfaces explained the analogous circumstance, that as soon as the action of a railway brake-block reduced the speed of the wheel below that of the speed of the train, skidding ensued, and then there was no alternative but to ease the brake till the wheel turned freely, and to re-apply it judiciously.

During the period immediately following his retirement from professional work, Mr. Froude was by no means idle. As Justice of the Peace, and as Trustee for several Turnpike Trusts, he had a good deal of general occupation. In these and similar positions his engineering and scientific knowledge naturally threw upon him the burden of advising his colleagues on technical matters. He also for many years took an active part in the Bath and West of England Agricultural Society, as one of the judges of the machinery exhibited. He constructed a dynamometer for testing the engines and machines, and, with the view of rendering its employment acceptable to competitors, published in the Transactions of the Society[1] an explanation of the principles of the instrument and of the machines whose behaviour it was intended to record. He also contributed valuable reports to the Society on the machines exhibited and on the principles involved in their action.

In connection with the waterworks of Torquay, Mr. Froude rendered important service. Within a short time after the works were completed, the delivery of water through the supply main, 15 miles long, proved to be only about one-half of what it should have been. All kinds of theories and explanations were propounded. Mr. Froude, being called into council, proceeded, as was his habit, to make a scientific examination of the circumstances of the case. By careful measurements of the pressure at various points throughout the main, he found that the defect in the power of the pipe to carry the water was manifested equally throughout the whole length. It thus became evident that the defective delivery was due to the increased friction of the pipe, caused by rust on its interior surface. This fact having been proved, Mr. J. G. Appold,

[1] Bath Soc. Journ., vol. v. (1857), pp. 216–277.

Assoc. Inst. C.E., just before his death, suggested that a piston, propelled along the pipe by the pressure in the main, might carry knives to dislodge the rust, which would then be cleared away by the flow of the water. Mr. Froude adopted the suggestion, and constructed a machine, by which the delivery of the main was raised even above the calculated delivery, and the town of Torquay was thus saved for nearly twenty years the expenditure of about £30,000 on a new main.

In his leisure Mr. Froude occupied himself a good deal in mechanical handiwork. His skill as a worker in material was great, and resulted from the educated knowledge of what should be aimed at, rather than from any particular excellence in that kind of aptitude which artizans acquire from practice. Even in ordinary work, he made use of well directed refinements of measurement for saving time. He was free from superstitious belief in the automatic accuracy of machine tools, and preferred to trust principally to gauges and surface plates, having a maxim that any error which could be detected could always, with proper care, be corrected. At the same time he did not neglect to employ all the advantages that good tools could afford. His lathes were kept in perfect order; there was no slackness, nor, what he seemed still more to dislike, any unnecessary tightness. Nothing was suffered to remain wrong. It must not, however, be supposed that he was a slave to nicety of work and of fit. He knew well, where and when this was important; and he was never content with a suggested cause for the defective working of any machinery, until, by putting the matter into quantities, he had satisfied himself that the cause was not only right in kind, but was also sufficient to produce the observed effect. He would often caution others against the temptation, as he expressed it, "to over-estimate tendencies." His experimental apparatus always exhibited excellently finished work where finished work was necessary, and sufficiently though less finished work in other parts.

Among the more remarkable scientific inquiries undertaken by Mr. Froude, on subjects other than those relating to naval architecture, was that "On the Law which governs the discharge of Elastic Fluids under pressure," as to which he presented a Paper to the Institution in 1847.[1] In that communication he pointed out certain misconceptions in the received theory as to the flow of gases, and suggested important improvements in the treatment of the question. Another subject of general scientific interest which

[1] *Vide* Minutes of Proceedings, vol. vi., p. 356.

he investigated theoretically, and which it was always his hope still further to work out experimentally, was the resistance experienced by a plane moving obliquely through a fluid, especially as regards the practical exemplification of the theory in the flight of birds.

Before describing his later work it should be mentioned that on the death of his father, in 1859, Mr. Froude left Dartington and went to live at Paignton in Torbay. He afterwards built a house, known as Chelston Cross, on the hill immediately above the Torquay railway station, and upon the design and construction of this house, which he first occupied in the year 1867, much care was bestowed. About the same date came his opportunity of employing his talents to a pursuit of inestimable value to the nation, one for which he was eminently fitted, and to which thenceforward his whole time and powers were devoted.

From his earliest days at school at Westminster, and again while at Oxford, Mr. Froude had been well known for his management of boats; and later on as a skilful yachtsman he paid frequent attention to many of the problems, such as the resistance of the hull, the effect of the wind on sails, the action of the rudder, and the like, which became matters of more careful study in later years. It was partly with an intention of determining the best form for a yacht which he proposed to build, that he commenced a series of experiments on the resistance of models,[1] which were the germ of the Admiralty experiments he afterwards conducted at Torquay. Having friends in the Royal Navy, he had many opportunities of becoming familiar with the progress of naval architecture, and shortly after the introduction of the screw propeller into the navy, he was struck by the disadvantageous position in which the screw was placed, especially in the converted line-of-battle ships, and he thereupon made some instructive experiments with a model. He urged the consideration of this detrimental action of the screw for twenty years, but with little effect.

In his younger days, when at Bristol, he saw much of the "Great Western" and "Great Britain" steamships, and during the construction of the "Great Eastern" he, at Mr. Brunel's request, undertook the investigation of the rolling of ships. His researches on this subject at once attracted attention. The behaviour of waves and of a ship among waves had hitherto been looked upon either as an insoluble problem, or as one in which the solution arrived at would have no real counterpart in the

[1] *Vide* Trans. Inst. Naval Architects, vol. xi., 1870, p. 86 *et seq.*

actual circumstances of practical experience. Mr. Froude showed how both the motion of the waves and of vessels could be reduced to rule, and could be mathematically, and indeed mechanically, explained. He investigated the matter in its general features, and also in many of the intricacies involved in the behaviour of abnormal forms of ships; and further, by his aptness in experimental inquiry and by his mechanical skill, he was able to devise apparatus which measured quantitatively the behaviour and characteristics of ships rolling in still water and among waves, and gave at the same time an accurate record of the form of the waves in which the vessel was at the time oscillating.

It has been said that experiments on the yacht model forms were the germ of Mr. Froude's experiments on the resistance of ships. His first step, in connection with this subject, was to enunciate the true principle of the relation of the resistance of a ship to that of her model, namely, that the resistance is in the proportion of the cube of the linear dimension at speeds proportional to the square root of the linear dimension. He demonstrated this mathematically, and by experiments with different-sized models, some of which were nearly ½ ton in displacement. Mr. E. J. Reed, M. Inst. C.E., when Chief of the Constructive Staff of the Navy, encouraged Mr. Froude to propose to the Admiralty to conduct a series of experiments on the resistance of models. The offer was accepted in the year 1870, and from that time, except when occupied on other work for the Admiralty, Mr. Froude devoted his energies to the conduct of experiments for the Government on the resistance of ships, and on the cognate subject of their propulsion. The Admiralty establishment at Torquay, erected by Mr. Froude for carrying out these experiments, contains a covered tank 250 feet long, 33 feet wide, and 10 feet deep. Above this tank there is a suspended railway, on which runs a truck drawn at any given speed with great exactness, and beneath this truck the model is drawn through the water, and its resistance is measured by a self-acting dynamometer on the truck. There are also arrangements for testing the effect of screw propellers behind the models. The machinery for manufacturing models, and the various governors for regulating and recording speed, are evidences of Mr. Froude's scientific skill. The establishment has also been used for other inquiries allied to its original purpose; but that purpose has been at the same time steadily pursued, and an exhaustive series of experiments on the forms of ships has been in progress, from which valuable results have been obtained; and for the Royal Navy all the proportions and forms have been

subjected to the investigation given by the experimental apparatus at Torquay. In these inquiries Mr. Froude appreciated and demonstrated the true bearing of the doctrine of stream-lines, and the qualifications that had to be introduced to reconcile the simpler forms of that doctrine with the condition of a ship moving at the surface of the fluid, and he was thus able to establish the true methods of research which he pursued. His general conceptions of the bearing of the stream-line theory on the resistance of ships were described in his address as President of the Mechanical Section of the British Association at Bristol in 1875, an address which was afterwards delivered as a lecture at the Royal Institution on the 12th of May, 1876.

His knowledge of pure mathematics was considerable, and he was also especially skilled in employing graphical methods for the solution of the large class of problems in which algebraic expressions become inconveniently complicated. An instance of this method may be found in his Paper "On the Graphic Integration of the Equation of a Ship's Rolling, including the Effect of Resistance," read at the Institution of Naval Architects in 1875.

Mr. Froude's researches into the expenditure of power in screw ships, the proportions of screw propellers,[1] and the information to be deduced from the speed-trials of ships, are of immense importance, not only to the Royal Navy, but also to the Mercantile Marine. In connection with this subject the Admiralty asked him to design a dynamometer capable of determining the power of large marine engines. The very remarkable machine which he devised to meet the requirements of this problem was not tried on a large scale in his lifetime. He finally inspected the completed machine just before he last left England, and its experimental trials have since taken place with great success. Mr. Froude explained the principle of the invention at the meeting of the Institution of Mechanical Engineers at Bristol in 1877, and subsequently referred to it at the Institution of Civil Engineers.[2]

Mr. Froude's value as an adviser in naval architecture was publicly recognised by his appointment as a member of the "Committee on Designs," in 1870, and as a member of the "Inflexible" Committee in 1877; but it was shown still more by the friendly confidence accorded to him by the Constructive Staff and by the

[1] In 1871, in the course of a discussion at the Institution he contributed what amounted in reality to an independent essay on the action of the screw propeller. *Vide* Minutes of Proceedings, vol. xxxii., pp. 232–248.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. li., pp. 38–44.

successive heads of the Admiralty. Nothing perhaps demonstrated more strongly the endearing qualities which Mr. Froude possessed than the manner in which he was treated wherever his work for the Admiralty took him. In the dockyards, and on board the many ships of the Navy where he conducted experiments, his work was necessarily an interference with the regular routine, and frequently with the habits of thought of those among whom he came; but so fully did he feel and express his appreciation of this, and such was his unfailing tact and consideration for others, that the desire of all was to assist and welcome him; indeed, it was a pleasure to go an errand for him, so cordial was the reception which the mention of his name ensured. Wherever Mr. Froude went he was beloved, but nowhere perhaps will his memory be more cherished than among the officers of the Admiralty and of the Royal Navy.

Mr. Froude was elected a Fellow of the Royal Society in 1870, and in 1876 he received the honorary degree of LL.D. from the University of Glasgow. In the same year he received the Royal Medal from the Royal Society, on which occasion the President, in his address, said:—

"A Royal Medal has been awarded to Mr. William Froude, F.R.S., for his researches, both theoretical and experimental, on the Behaviour of Ships, their oscillations, their resistance, and their propulsion.

"It is generally admitted that Mr. Froude has done more than anybody else towards the establishment of a reasonable theory of the oscillation of ships in wave-water, as well as for its experimental verification. The very accurate instruments which he has contrived for the measurement of a ship's oscillation at sea have even permitted him to measure (as a differential phenomenon) the mean wave acting upon the ship with a degree of exactness exceeding that with which it has hitherto been possible to ascertain the profile of the surface-wave of the sea.

"He was also the first to establish on thoroughly sound principles the mechanical possibility of that form of motion known as the trochoidal sea-wave, which more nearly than any other appears to represent the shape of smooth ocean-wave, and which now forms the groundwork of all useful theories of the oscillation of ships.

"He has also conducted a series of experiments, extending now over many years, on the Resistance, Propulsion, and Form of Ships, and on the very important and little-understood question of the law connecting the behaviour of ships, in all these respects, with

that of models of ships on a much smaller scale. These experiments have been conducted partly for the Government, and with public money; but they have also very largly taxed Mr. Froude's own private resources, the sums repaid to him by no means representing his whole expenditure on these matters, and including no compensation whatever for his own time or labour.

"The amount of mechanical skill, as well as of theoretical acuteness, which has been exhibited in all this work has placed Mr. Froude in the foremost rank of all investigators on this subject. No one, indeed, has ever done more, either theoretically or practically, for the accurate determination of a ship's motion, whether in propulsion or in waves, than Mr. Froude. Without undervaluing other modern writers, it is not too much to say that his investigations at present take completely the lead in this very important question—most important to a maritime nation."

Mr. Froude became a Member of the Institution of Civil Engineers in 1846, and in 1877 he was elected a Member of Council. The serious illness and death of his wife almost entirely prevented his attending the meetings of the Council. In the winter of 1878, on the invitation of Commodore Richards, he went on a cruise to the Cape, in H.M.S. "Boadicea," and was about to return to England, refreshed in body and mind, when he was seized with an attack of dysentery, and died at Admiralty House, Simon's Town, after a short illness, on the 4th of May, 1879. His body was followed to the grave in the Naval Cemetery by the officers and men of Her Majesty's ships then in Simon's Bay, in recognition of the great services he had rendered to the Royal Navy.

The following is a list of the more important Papers, arranged in chronological order, contributed by Mr. Froude to various societies:—

"On the law which governs the discharge of elastic fluids under pressure, through short tubes or orifices."—Minutes of Proceedings Inst. C.E., vol. vi., 1847, pp. 356–384.

"Remarks on mechanical power and description of a new dynamometer."—Bath Soc. Journ., vol. v., 1857, pp. 216–237.

"On a new dynamometer and friction break."—Inst. of Mech. Eng. Proceedings, 1858, pp. 92–110.

"On the rolling of ships."—Trans. Inst. Naval Architects, vol. ii., 1861, pp. 180–227; vol. iii., 1862, pp. 45–62.

"On isochronism of oscillation in ships."—Trans. Inst. Naval Architects, vol. iv., 1863, pp. 211–215.

"Remarks on the differential wave in a stratified fluid."—Trans. Inst. Naval Architects, vol. iv., 1863, pp. 216–218.

"Remarks on Mr. Scott Russell's Paper on Rolling.—Trans. Inst. Naval Architects, vol. iv., 1863, pp. 232–275.

"Remarks on the mechanical principles of the action of propellers."—Trans. Inst. Naval Architects, vol. vi., 1865, pp. 35–39.

"On the practical limits of the rolling of a ship in a sea-way."—Trans. Inst. Naval Architects, vol. vi., 1865, pp. 175–184.

"Apparent negative slip in screw-propellers."—Trans. Inst. Naval Architects, vol. viii., 1867, pp. 70–81.

"On some difficulties in the received view of fluid friction."—Brit. Assoc. Rep., vol. xxxix., 1869 (Sect.), pp. 211–214.

"On the action of the screw-propeller."—Minutes of Proceedings Inst. C.E., vol. xxxii., 1870–71, pp. 232–244.

"On the influence of resistance upon the rolling of ships."—"Naval Science," vol. i., 1872, pp. 411–429; vol. iii., 1874, pp. 107–121 and 312–330.

"Experiments on the surface-friction experienced by a plane moving through water."—Brit. Assoc. Rep., vol. xlii., 1872, pp. 118–124; "Nature," vol. vi., 1872, p. 387.

"Description of an apparatus for automatically recording the rolling of a ship in a sea-way."—Brit. Assoc. Rep., vol. xlii., 1872 (Sect.), pp. 243–245.

"Description et usage d'un pendule à tres-longue période pour la mesure du roulis absolu." (*In English.*)—Cherbourg, Mém. Soc. Sci. Nat., vol. xvii., 1873, pp. 203–208.

"Considerations respecting the effective wave slope in the rolling of ships at sea."—Trans. Inst. Naval Architects, vol. xiv., 1873, pp. 96–108; "Naval Science," vol. ii., 1873, pp. 215–239.

"Description of an instrument for automatically recording the rolling of ships."—Trans. Inst. Naval Architects, vol. xiv., 1873, pp. 179–184.

"Apparatus for automatically recording the rolling of a ship in a sea-way, and the contemporaneous wave-slopes." Journal of the R. U. S. Inst., vol. xvii. 1873, pp. 858–884.

"On experiments with H.M.S. 'Greyhound.'"—Trans. Inst. Naval Architects, 1874, vol. xv., pp. 36–59.

"On Stream lines."—"Naval Science," vol. iii., 1874, pp. 504–507.

"On the graphic integration of the equation of a ship's rolling, including the effect of resistance."—Trans. Inst. Naval Architects, vol. xvi., 1875, pp. 57–71.

Address as President of the Section of Mechanical Science of the British Association.—Brit. Assoc. Rep., vol. xlv., 1875 (Sect.), pp. 221–239.

"The fundamental principles of the resistance of ships."—Roy. Instit. Proc., vol. viii., 1875–78, pp. 188–213.

"Experiments upon the effect produced on the wave-making resistance of ships by length of parallel middle body."—Trans. Inst. Naval Architects, vol. xviii., 1877, pp. 77–97.

"On the elementary relation between pitch, slip, and propulsive efficiency."—Trans. Inst. Naval Architects, vol. xix., 1878, pp. 47–57.

MR. RICHARD LIONEL JONES, M.A., Dublin, was born in that city on the 21st of April, 1841, where his family had resided for five generations. He was educated in the school of the Rev. Daniel Flynn, D.D., and passed thence in the year 1858 into Trinity College. He decided on following the profession of a Civil Engineer, and with that view joined the engineering school attached

to the University, where he studied diligently, and obtained the degree of Bachelor in Arts and a diploma in civil engineering at the end of 1862. He had already spent one year as a pupil and an assistant to the late Mr. Marcus Harty, the engineer of the Dublin and Drogheda railway, and remained in the same office for another year. His next employment was in London, where for two years he was engaged under different engineers, chiefly upon railway and drainage works. In the early part of 1866 he joined the engineering staff of the London, Chatham, and Dover railway, as an assistant to Mr. William Mills, M. Inst. C.E., the engineer of that line, under whom he was occupied mainly in the drawing office until the end of 1871, when he was selected to take charge of the construction of the Holborn Viaduct railway and station, upon the designs for which he had been engaged. These works were carried out by him in a highly creditable manner, and on their completion he was entrusted with their maintenance, and with other important works of construction.

In 1874 he was elected an Associate of the Institution of Civil Engineers, was admitted in the Michaelmas term of 1878 to the degree of Master in Arts at his university, and on the 31st of December of that year was transferred to the class of Member of the Institution.

He was a man of a high sense of honour, of a keen and kindly wit, and an amiable disposition; he possessed in a remarkable degree the faculty of exposing fallacies in a convincing manner, and he had the power of attracting to himself without effort the alliance and affection of other men. Both in professional matters and in private life, his practical turn of mind and lucidity of expression obtained for his opinions marked attention. His work was always thoroughly sound and reliable, the details being invariably well considered.

Mr. Jones died on the 4th of November 1879, from inflammation of the lungs, after a short illness.

Mr. FRANCIS CHEESMAN, fifth son of Mr. Robert Cheesman, of Westwell, Kent, was articled for four years in November 1864 to Messrs. Eastons, Amos, and Anderson. In February 1869 he was engaged under Mr. H. C. Anderson, M. Inst. C.E., in the erection of large paper mills, for the Viceroy of Egypt, at Boulak, and of sugar mills at Bene-Mazar and at Aba,[1] for which Messrs. Eastons

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxv., pp. 37–70.

and Co. were the contractors, and he remained in Egypt until the end of 1873. In February 1874 he undertook the erection of a paper-making mill at Ogi, Japan, for the Japan Paper Making Co. This work was under his sole charge, and was completed very quickly, nearly the whole of the labour being done by Japanese workmen.

Mr. Cheesman returned to England in 1877, and, on the 1st of January 1878, entered into partnership with Messrs. Clayton and Howlett, engineers and ironfounders, where he remained until his sudden death, from heart disease, at the age of thirty-one, on the 15th of January, 1879.

As an evidence of his character, a friend writes: "That he was a man of wonderful self-possession: nothing seemed to disturb him or put him out. He used to go about his work in a quiet, determined manner, which had the effect of making the natives obey him. He also picked up languages very quickly."

MR. CHARLES ARCHIBALD GRIEVE was born on the 24th of April, 1851, at Dumfries, where his father was in practice as a physician, and at the Academy in that town his education was received. The profession of an engineer being the one for which he seemed best fitted, his turn of mind from boyhood being thoroughly mechanical and practical, in October 1868 he became a pupil of the late Mr. Williams Johnstone, M. Inst. C.E., on the Glasgow and South-Western railway. In December 1872 he entered the office of Messrs. Blyth and Cunningham, as an assistant, and was employed in office and field work, giving such satisfaction for accuracy, intelligence, and energy, that in September 1874 he was appointed by that firm Resident Engineer on the Carlisle Citadel Station Extension works, which embraced the construction of 13 miles of railway, besides the enlargement and remodelling of the station.

In 1877 Mr. Grieve's health gave way, and he made a voyage to India, under medical advice. He returned in a few months, apparently much improved in health, and resumed his duties; but the winter of 1877-78 again warned him that he must seek a warmer climate. Fortunately an opening soon occurred under Mr. H. C. Stanley, M. Inst. C.E, chief engineer of the Southern and Western railway of Queensland. He arrived at Brisbane in October 1878, and immediately entered upon his duties as principal office assistant. He appeared to gain strength, but was cut off suddenly on the 25th of July, 1879. Mr. Stanley wrote of him: "During

the short time he was with me, he became a general favourite, and his loss was much felt by all with whom he had been associated in the service. I found him a most valuable assistant, and a pleasant and genial friend."

Mr. Grieve was elected an Associate of the Institution on the 2nd of April, 1878.

MR. JOHN ATKINSON HARRISON was born at Gateshead-on-Tyne on the 10th of October, 1816, and was the only son of Mr. J. A. Harrison, tanner, of that town. His general education was obtained at the endowed grammar school at Morpeth. His professional career commenced by his being articled to Messrs. R. and W. Hawthorn, when he went through the usual routine of apprenticeship in the workshops and in the drawing office. On the termination of his articles in 1845, he entered the office of the late Mr. Robert Nicholson,[1] M. Inst. C.E., as an assistant and improver, where he remained until the death of Mr. Nicholson in 1855, seeing his full share of a large and varied practice. He was next engaged on various Parliamentary and other surveys in Northumberland, Durham, Yorkshire and elsewhere, for the Border Counties, the Blyth and Tyne, and the Severn Valley railways for Mr. J. F. Tone, M. Inst. C.E., the successor of Mr. Nicholson, by whom he was appointed Resident Engineer on the Morpeth branch of the Blyth and Tyne railway in 1856, upon which he was employed for two years. Mr. Harrison was then constantly occupied on the surveys for the Parliamentary contests between the North British and the Caledonian Railway companies, which ended in the making of the Border Union and the Border Counties Extensions by the North British Co. In 1859 (when Mr. Harrison was elected an Associate of the Institution) he was appointed Resident Engineer on the three heaviest contracts on the Border Union railway—those from Hawick up to, and including, the tunnel through the "Limekiln Edge." Owing to the works on the Whitrope contract being after a time taken by the company into their own hands, great additional responsibility was thrown upon Mr. Harrison. This line was completed in 1863. Besides its interest to him as an ardent lover of nature and as a keen sportsman, Mr. Harrison's literary tastes made this long residence in a district which is pre-eminently the scene of border legend and minstrelsy a great and lasting pleasure. He now began private practice

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xv., p. 93.

in Newcastle, and was engaged in various matters connected with railway work, the preparation of plans for the Whittle Dene and other extensive waterworks, &c., interrupted from time to time by attacks of the disease which eventually proved fatal. In 1870 he became chief engineer of the Scotswood and Newburn railway, in conjunction with Messrs. Laws, MM. Inst. C.E.. After the Act was obtained, and the designs were completed, he took personal charge of the works for about a year. His health becoming gradually worse, he was reluctantly compelled to abandon an active career, still however feeling a lively interest in all that went on, and working when favourable weather, or a temporary improvement in health, made it possible. For the last few years he resided at Wylam-on-Tyne, where he died suddenly on the 14th of February, 1880, from the bursting of an aneurism, of the gradual formation of which he had long been aware. Mr. Harrison's kindly and genial temperament, and the store of information and anecdote with which his wide reading and varied experience supplied him, made him a universal favourite, especially among his professional brethren, the younger members of whom he was always ready to advise and assist.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Remarks on the accuracy attainable in Spirit-Levelling.

By W. SEIBT.

(Civilingenieur, vol. xxv., col. 353.)

The Author proposes to settle definitely these three questions, viz.:—

1. The method of observing which shall ensure the highest degree of accuracy.
2. The most favourable distance for reading the staves.
3. The most suitable plan for weighting the observations.

After carefully examining, in the first place, the results obtained by Hagen and Jordan—as these have hitherto generally formed the basis for all theories on this subject—he gives it as his opinion that both are unsatisfactory and inconclusive on these points; Hagen's, chiefly on account of the very imperfect instruments used by him in comparison with those of the present day, and Jordan's, because his observations were made under conditions which hardly ever obtain in ordinary levelling, inasmuch as they were taken in one direction only, and were adapted more for fixing the constant of a distance-measuring telescope, than for determining the accuracy attainable in finding differences of height. Jordan's readings were taken exclusively by the upper and lower cross-hairs without, for the most part, any corrections for dislevelment. The Author's results are calculated from observations made during the summer of 1878,—though under no exceptional circumstances,—for the special object of this Paper. His telescope of 18-inch focal length had a magnifying power of 42, and an object-glass of $1\frac{5}{8}$-inch aperture, besides a very sensitive level. The staves were divided into alternate black and white spaces, each 4 millimètres (0·16 inch) wide, the mean error in their graduation being $\frac{1}{25}$ millimètre. The instrument was *always* set up midway between the back and forward staves, and the observations taken by one central cross-hair, both ends of the telescope-level being invariably read at each observation. The staves were read at distances of 50, 100, 150, and 200 mètres (164, 328, 492, and 656 feet), twenty-four pairs of observations being taken at each; these distances were laid off by the staves, and checked by Reichenbach's telemeter. Observations were only made on a still, clear day, the back and fore sights being taken as soon as possible after one another; each complete observation occupied about six minutes,

and care was taken that at each distance the smallest detail of the staff should be distinctly visible.

The instrument was set up afresh at each pair of observations when the staves were 200 mètres distant; in all other cases the back and fore sights were repeated three or four times. The observations were never reduced in the field, and no single reading was rejected from the calculation, however different from the one next to it.

Detailed Tables are given of all the readings and calculations, whence it is proved that the mean error m in an observation consisting of a back and forward reading, after the application of every correction, is as follows, viz.:—

At 50 mètres, $m = \pm\ 0\cdot30$ millimètre.
" 100 " $m = \pm\ 0\cdot57$ "
" 150 " $m = \pm\ 0\cdot76$ "
" 200 " $m = \pm\ 0\cdot89$ "

Hagen and Jordan having observed at other distances than the above, the Author has compiled the following Table, showing the mean error in the work of all three observers at the same distances, from which it is evident that his method of observing is much more accurate than either Hagen's or Jordan's.

Length of Sight in Mètres = 3·28 feet.	Mean error in Millimètres of an Observation consisting of one back and one fore sight by		
	Hagen.	Jordan.	Seibt.
	* = Observed and Corrected. † = Interpolated.	* = Observed and Corrected. † = Interpolated.	* = Observed and Corrected. † = Interpolated.
19	1·4*	..	..
30	1·7†	0·44*	0·17†
38	2·0*	..	..
50	2·3†	0·80†	0·30*
60	2·6†	0·99*	0·36†
75	3·1*	..	..
90	3·5†	1·68*	0·52†
100	3·8†	1·91†	0·57*
113	4·2*	..	..
120	4·4†	2·46*	0·65†
132	4·8*	..	..
150	5·3†	3·36*	0·76*
151	5·3*	..	..
180	6·2†	4·38*	0·85†
188	6·5*	..	..
200	6·7†	5·16†	0·89*
210	7·0†	5·58*	0·91†
226	7·6*	..	..

For the second question a Table is given showing, for sights 50, 100, 150, and 200 mètres long respectively, the increase in the

mean error per kilomètre as deduced from the results of the three observers. From this the superiority of the Author's work is still more apparent; his observing even at the longest distance (200 mètres) shows only a mean error per kilomètre of 1·41 millimètre in compound observations (as against 10·6 of Hagen's, and 8·16 millimètres of Jordan's), and of only 0·70 millimètre in back and fore sights which are repeated four times. He thence argues that such accuracy is so great that no advantage, as a rule, is gained by observing at shorter distances than 200 mètres, as they entail expense, time, and labour incommensurate with the accuracy to be derived from them.

To sum up, the distance for observing should be limited by the capacity of the observer and of his instrument; this will always be rightly chosen when it, on the one hand, is so far extended within those limits as always to take in the terrain on which the levelling is carried out, and, on the other hand, is so far contracted that no trace of air-movement is noticeable in the telescope, but a perfectly stationary and sharp image of the staff is represented. Acting strictly on this principle, the Author asserts that the mean kilometric error, with good instruments, should not exceed 0·64 millimètre, as in extensive levelling operations the distance for reading the staves does not usually exceed 100 mètres (328 feet). That such a degree of accuracy is not unattainable he proves by an example from some of his own levelling in the Saxon-Prussian boundary.

As regards, in the third place, the weight to be assigned, supposing a large district S, composed of

a_1 stations,	observed	with	sights z_1 long,	whose	mean	station	error	$= m_1$
a_2	,,	,,	,, z_2	,,	,,	,,		$= m_2$
a_3	,,	,,	,, z_3	,,	,,	,,		$= m_3$
a_n	,,	,,	,, z_n	,,	,,	,,		$= m_n$

then the mean error of the district composed of a stations $= \sqrt{[a\,m^2]}$.

The weight p of the district S is by the method of least squares equal to the reciprocal value of the square of its mean error, or

$$p = \frac{1}{(a\,m^2)}.$$

Therefore, if sights of equal lengths are taken for the whole district, A is the total number of stations, and m is the mean error per station for those sights, the mean error of the district composed of A stations

$$= m\sqrt{\mathrm{A}}, \text{ and}$$

$$p = \frac{1}{\mathrm{A}m^2}.$$

In this way a weight may very simply be assigned to levellings carried out with known staff distances where the level is always midway between the staves, when the accuracy of any observer's work is known, and thus the measurements of different observers

may be joined together at their *true values*. Practice must decide whether this method of assigning weights works so favourably and satisfactorily in very large levelling operations as to preclude further investigation of the subject.

E. H. C.

Periodical Movements of the Ground as Indicated by Spirit-levels.

By M. Plantamour.

(Comptes rendus, vol. lxxxix., p. 937. Archives des Sciences Physiques et Naturelles, vol. ii., p. 641.)

This Paper communicates further results of the investigations commenced in April and May 1878 on the bubble-displacement of spirit-levels at Sécheron, Lake of Geneva.

The levels (previously described [1]) were remounted with fittings specially made, in order to prevent any chance of displacement when turned through 180°, and set up on a masonry table, which had been built twenty years. One level pointed east and west, the other north and south; their bubble-movements were measured on brass scales divided to millimètres, which, by practice, the Author could subdivide to tenths of a millimètre; these readings were taken as rapidly as possible by the help of a wax taper. During the summer of 1878, the gradual elevation of the east end continued (as in the spring), but in the latter half of September a depression set in, which decided the Author to make continuous observations for a whole year, viz., from 1st October, 1878, to 30th September, 1879. These observations were taken five times a day, at 3 hours' interval, from 9 A.M. to 9 P.M., the mean of the five readings giving the bubble-position for the day. Curves of this position were thus obtained on sectional paper, the distance representing horizontally one day, and vertically one millimètre of bubble-displacement, which corresponds to an angle of 0·537 second for the curve of the east end, and of 0·415 second for the south curve.

During October and November the depression of the east end continued, though with some slight returns to the west, and observing that such depression coincided with the lowering of the temperature, M. Plantamour plotted also on his diagram the curve of the mean daily temperature, the space between each ordinate corresponding in this case to 1° centigrade. The coincidence between the ground movements, as indicated by the bubble, and the temperature was now evident, the curves representing these being nearly identical up to 30th of June, though from then till 1st September the rise in the east end far exceeded that in the temperature. This, however, is attributed to the heat stored up in the ground itself, which exerted an influence superior

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. liv., p. 286.

to the air-temperature. After 8th September both the east end and the temperature fell suddenly. The maximum depression of the east end (− 32·8 millimètres) occurred on 15th January, the maximum elevation (+ 19·5 millimètres) on 8th September; the total amplitude of the oscillation of the ground from east to west during the year was therefore 52·3 millimètres, or 28·08 seconds.

A diurnal movement was also noticed, whose amplitude varied from 0 to 1, 2, and even to 3·2 seconds on 5th September. By means of Bessel's formula for periodical phenomena, values were found for the three periods, midnight, 3 A.M. and 6 A.M., at which no readings had been taken, and it is thence proved that the maximum and minimum diurnal movements generally occur between 6 and 7.45 o'clock evenings and mornings.

The ground movements indicated by the level in the meridian present a strange anomaly, for though from 23rd December, 1878 (when readings commenced), to 30th April, 1879, the oscillations of the south end, though much weaker, agree with those of the east end, from the 1st of May a gentle, but gradual depression of that end set in, while the east end and the temperature both rose rapidly. Besides this, the sudden oscillations, occasioned by great changes of temperature during this continuous movement, occur in this case in a *contrary direction* to that observed in the east curve. Further investigations must be made to explain this. The total amplitude of the oscillation in the meridian has been only 4·89 seconds for the nine months. The diurnal movements are also rare, and always very slight and irregular. M. Plantamour is hence led to believe that the movements of the ground in the direction east to west are caused by variations in the temperature, but that in the direction of the meridian they are not due solely to this cause; some other, as yet unknown, agency is also at work, and with a counteracting influence; the configuration, and perhaps also the geological nature of the district very probably influence their intensity.[1] Thus, observations carried on for a whole year (1856) at Paris indicated no ground movement, while at Geneva a slight annual movement from east to west has been established. At Neufchatel, 177 feet above the lake, Professor Hirsch has, from a very long series of observations, detected an annual movement from east to west, of which the amplitude is 23 seconds, besides an azimuthal movement of 75 seconds, but these he attributes to thermic action. Lastly, at Berne, a marked diurnal movement has been traced, though not an annual one, owing to insufficient observations.

E. H. C.

Note.—M. Plantamour only discovered at the close of his observations that the declination of the compass, by which his levels had been set up, was 22° in place of 15°; it is hence probable that the movements of the south end were influenced somewhat by those of the east end, and that they would have been still weaker had the levels been correctly set up.

[1] The soil at Sécheron is a stiff clay.

Notes on Cement.

(Dingler's Polytechnisches Journal, vol. ccxxxiii., pp. 387 and 473.)

A commission of architects and cement manufacturers, named by the Minister of Commerce, have made some alterations in the German standard rules for testing cement. The residue to remain upon a sieve of 5,806 meshes per square inch has now been reduced to 20 per cent. instead of 25 per cent. Tests made with neat cement are only to be regarded as a means of controlling the uniformity of different parcels, not as a final index of quality. The minimum strength of a mixture of 1 part cement with 3 parts sand in twenty-eight days, has been increased to from 113·8 lbs. per square inch to 142 lbs. per square inch.

Tables are given showing the effect which the quality of the sand used exercises upon the strength of the mortar. Standard silicious sand from various localities was found to give very different results when mixed with the same cement. A mixture of 3 parts sand with 1 part cement gave results varying from 156 to 213 lbs. per square inch in twenty-eight days, according to the kind of sand used. Tomeï's researches on the influence of sulphates on cement[1] are illustrated by Tables.

W. F. R.

On Testing Cement. By Dr. Frühling.

(Thonindustriezeitung, vol. iii., p. 43 *et seq.*)

The Author describes an apparatus of his invention for measuring the permeability of hydraulic mortars. The sample of mortar to be tested is in the shape of a circular slab, and is inserted between two flanges which unite the upper and lower halves of a copper vessel. The joint having been made watertight by means of screws and indiarubber rings, water is admitted into the upper half of the copper vessel, and subjected to the pressure of a column of water or mercury. All water which passes through the sample is caught and measured in a graduated glass vessel placed below the funnel-shaped lower half of the copper vessel. The pressure employed can be regulated as required.

Raasche and Michaëlis have described modifications of this apparatus;[2] the former produces the water-pressure by means of a force pump; the latter uses a partial vacuum below the sample tested.

Dr. Erdmenger recommends a method of making briquettes for

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lviii., p. 365.

[2] *Vide* "Dingler's Polytechnisches Journal," vol. ccxxxiii., p. 318.

testing, which he has found to give uniform results. The cement, as is now usual in Germany, is mixed with 3 times its weight of standard sand, and then with 12–14 per cent. of water. The moulds are placed close together upon an iron slab previously covered with a piece of brown paper. The soft cement mortar is then placed in the moulds and the surface smoothed with a trowel. Before the mortar sets the moulds are slipped off the briquettes, the latter remaining undisturbed upon the slab for twenty-four hours, when they are immersed in water. Briquettes made in this way are said to give more uniform results than when they are allowed to set in the moulds, although the strength obtained is not so great as when less water is used.

W. F. R.

Experiments on the Strength of Iron and Steel.

By L. SPANGENBERG, Professor at the Technical High School, Berlin.

(Glaser's Annalen für Gewerbe und Bauwesen, vol. v., p. 6.)

The Author refers to the well-known researches of Wöhler on the strength of iron and steel under long-continued strain, to the classification proposed by him, and to the appointment of a government commission to deal with the matter. The mechanical part of the work of this commission was placed in the Author's hands. A Werder testing machine, maximum pull 100,000 kilograms (100 tons) was erected, and a Klebe measuring apparatus was supplied, measuring to $\frac{1}{5000}$ millimètre ($\frac{1}{125,000}$ in.), as well as various other instruments for conducting the experiments. With this apparatus a large number of experiments have been made. One series was designed to test the truth of Wöhler's three laws, which are:—

(1) Fracture may be produced by the continual repetition of oscillating stresses, all of them much below the breaking stress. It is the differences of strain, defined by the extent of the oscillations, which then produce fracture.

(2) The absolute value of these stresses only enters into the question so far that the greater this value the smaller are the differences which will finally produce fracture.

(3) When the resistance of a material to one form of stress has been found by experiment, its resistance to all other forms can be deduced by calculation.

The Author's experiments have confirmed the truth of the first law. With regard to the second, they are not yet complete. They do not agree with the third, inasmuch as experiments on transverse strain showed a much greater tensile resistance in the most heavily strained fibre than that given by direct experiments on tearing.

Again, on comparing experiments on Krupp's axle steel, made in 1863 by Wöhler, and in 1873 by the Author, it appears that in the interval the material had been greatly improved in its resistance to the ordinary stresses of axles, but had diminished in its resistance to direct tension. This latter is, of course, no real defect, and is, no doubt, due to an alteration in chemical composition; but it shows that tensile tests alone will not indicate the character of a material, and also how necessary it is frequently to repeat such experiments.

The Author has further endeavoured to investigate the connection between the appearance of fracture and the molecular changes, in pieces broken by repeated strains. His theory is that under such strains the texture of the metal is gradually changed from the crystalline to the amorphous. There thus arise different states of equal density of the molecules, each state having its own limit of elasticity. As the strains go on, these limits of elasticity are passed in the case of a continually increasing number of the molecules, and the piece is thus gradually weakened until rupture results. This he considers to accord with the molecular theory of Fourier and Redtenbacher, viz., that metals consist of crystalline molecules of attracting matter, each intermixed and surrounded with repelling ether. The action of strain would then be to break up the molecules into smaller and smaller elements. Hence is explained the fact that just at the point where rupture begins the fracture looks dull and amorphous (because the action has there been the most intense), while at a distance it is still crystalline. The rays, which are generally seen converging to this point of rupture, are due to a flow of surrounding molecules to the more heavily strained parts. In phosphor-bronze, broken by repeated strains, a flow of the phosphorus to the more extended parts is distinctly visible.

The theory is also in accordance with Bauschinger's result, that when a piece is slowly strained beyond its elastic limit, its ultimate strength becomes increased; for some of the molecules are thereby broken up, and when these have re-arranged themselves, their total strength is greater than before. The theory is also confirmed by experiments on sound. When the molecules have been broken up, the number of attractions existing within the piece is increased, and the velocity of sound within the bar should also be increased. The Author tried by Kundt's method the velocity of sound in a bar, first before testing, then after a million of bendings, and then after eight millions, and found the velocity to increase in each case. Beyond a certain limit two velocities were found to exist; one belonging probably to the part of the bar which had been in tension, and the other to that which had been in compression.

W. R. B.

On the Strength of Iron at High Temperatures. By J. KOLLMANN.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, 1880, p. 92.)

In this memoir the Author gives the results of a series of investigations carried out in 1877–78 at the Oberhausen works upon the tension and resistance to compression of wrought iron and steel at high temperatures, which, together with other experiments, were undertaken to obtain a basis for a theory of the action of the rolling mill and of the construction of rolls. The materials investigated were of three kinds, namely, fibrous malleable iron, fine-grained iron, and mild Bessemer steel, the samples used being of the average ordinary qualities produced in the works. Two testing machines were used: in one the strain was applied by hydraulic pressure, and in the other by weights applied directly. The elastic limit was determined by a contrivance called a multiplier, consisting of a pair of unequal armed levers with set screws on the shorter arms, whereby they are attached to the test piece. These remain closed while there is no permanent elongation, but when the limit of elasticity is reached the arms separate, the divergence being read off on a divided scale attached to the longer sides.

The experiments were made with test pieces of two different sizes; those for the smaller hydraulic machine were either round, of 13 millimètres (0·51 inch) diameter, or square of the same dimensions on the side. Those for the larger one measured 40 × 10 millimètres (1·575 × 0·394 inch). They were brought up to the required temperature by heating either in a coke fire or a portable forge; two exactly similar pieces being used, one for the experiment and the other for the determination of the temperature, which was done by means of a water calorimeter of a somewhat special construction. The final temperature of the broken test piece was sometimes determined in the same way, but generally the loss of heat was computed by observing the time and applying the results of a Table specially computed from masses of iron allowed to cool in the air for definite periods.

The experiments were made at temperatures varying from 20° to 1,080° Centigrade, and the progressive diminution in strength is expressed in terms of that at 0°, the latter being made = 100.

Centigrade.	Fibrous Iron.	Fine-Grained Iron.	Bessemer Iron.
°			
0	100	100	100
100	100	100	100
200	95	100	100
300	90	97	94
500	38	44	34
700	16	23	18
900	6	12	9
1,000	4	7	7

The resistance of iron to compression at the temperature at which it is usually rolled was estimated in two different ways; the first being by a loaded lever like that of a friction brake, acting on the top roll of the mill, and the second by a coiled spring placed between the top bearing and the set screw, the amount of pressure exerted by the pile in passing being measured by the weight lifted in the first instance, and by the diminution in height of the spring in the second. These results do not admit of graphic tabulation, as the amount varies with the diameter of the rolls, and the spread of the material in the grooves. This appears to be greatest at moderate temperatures. At a white heat malleable iron is so soft, and distorts so considerably, that it cannot be shaped to regular figures. Steel behaves somewhat similarly, but not to the same extent.

The remaining portion of the memoir describes numerous observations on the temperature of blooms and ingots taken at each pass of the rolling mill, and on the effect of different forms of grooves on the welding of piles, as tested by etched surfaces of the finished material. The Author finds that the so-called Gothic grooves are exceedingly objectionable, the material being squeezed together in an irregular fashion, while in flat rectangular grooves the work is more uniformly done. He therefore considers that the latter should be preferred in blooming rolls even although there may be greater facility of manipulation when gothic grooves are used. The practice of making the top roll of larger diameter than the bottom one to prevent the bar from coiling upon it, is also deprecated, as causing the upper layer of the pile to overrun the lower one, an effect which is especially marked in thin sections, such as hoop iron, which is generally broader at the bottom than at the top.

H. B.

On the Alteration in the Density of Steel through Hardening and Tempering. By C. Fromme.

(Annalen der Physik und Chemie, new series, vol. viii., p. 352.)

The experiments were made first on four bars of the same dimensions, 100 millimètres (3·9 inches) long, and 7 millimètres (0·27 inch) on the side, and then on bars of the same length but of different sections. The results obtained are as follow:—

After hardening in cold water the density decreases, or in other words the volume increases; the thicker the bar the less the increase.

After tempering the volume again diminishes, the increase being at "straw" reduced to one-half, and at "blue" to about one-fifth of the total increase gained after hardening, returning at "grey" to the original volume when soft. The molecular condition must,

however, be different, as the steel retains twice as much permanent magnetism in the "grey" temper as in the soft. If the bar is heated to a bright red and cooled slowly, the volume is larger than in the original state before hardening, the difference being about one-sixth the total increase gained after hardening. The question as to whether the density varies from the exterior to the interior of the bar, the Author proceeded to determine by eating off successive layers by acid, and determining the specific gravity of the remainder; but as a fissure was ultimately discovered inside the bar, the results must be considered untrustworthy. Further experiments in this direction are certainly desirable.

F. J.

On the Punching of Iron. By Prof. K. Keller.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereins, vol. xxxi., p. 163.)

The Author remarks that, since Tresca's classical papers[1] on the flow of plastic materials, there has been nothing published on punching, except a later Paper by Tresca,[2] and a record of some experiments made by Messrs. Hoopes and Townsend, together with Prof. Thurston, published in the "Journal of the Franklin Institute" for March 1878. The specimens of cold punching, exhibited at Paris in 1878 by the above firm, encouraged the Author to undertake experiments on this subject, the results of which are embodied in the Paper under consideration.

The experiments were carried out with a machine placed at the disposal of the Author by the Carlsruhe Maschinenfabrik. After being punched, the trial pieces were cut through and etched by a solution of platinum chloride, of a strength of 1 drop of chloride to 250 to 300 drops of water. The Author has found this solution to work better than any other; it brings out clear dark brown lamination lines, on a shining grey background; the lines are fixed by any non-acid animal oil.

The first effect of the punch is to cause a depression of the upper surface of the trial piece round the hole which is being punched; the material displaced from this depression flows downwards and outwards, and causes an enlargement of the base, so that the previously vertical sides of the test piece are caused to incline inwards.

As the punch proceeds, the material flows towards the point of least resistance, which is the hole in the bolster, and appears there as a button; the depth of this button is, however, considerably less

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[1] *Vide* "Comptes rendus de l'Academie des Sciences," vol. lxviii., p. 1197, and vol. lxx., pp. 27, 288, 368.

[2] *Vide* Proceedings of the Institution of Mechanical Engineers, 1878, p. 301.

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than the distance entered by the punch, showing that either a compression of the material must have taken place, or that there must have been a flow sideways of material into the body of the test piece.

To settle this point the Author undertook a series of specific gravity determinations, and found that the specific gravity of the whole punching was slightly less than that of the piece it was punched from. This result was also found by Messrs. Hoopes and Townsend, but was attributed by them to errors of observation; the Author found, however, by cutting the punching into layers, and determining the specific gravity of each separate layer, that the density of the punching increases towards the top; these results show that the lines of direction of pressure (and consequently a flow of material) curve outwards from under the punch into the body of the trial piece.

The etched lines show that originally horizontal layers are bent into wave lines, which stand nearly normal to the above-pressure lines, and which are gradually bent under the advancing edge of the punch till they become almost vertical at this place; when this moment is reached rupture by tearing commences; this ends the first period, called by the Author the period of compression or dislocation.

During the following period, or period of shearing, the resistance is less, compression ceases, and the punching is pushed out below at the same rate as the punch advances above, until it is finally entirely separated.

By equating the resistance to compression at the end of the first period to the resistance to shearing at the beginning of the second period, and using the equation thus obtained, in conjunction with the plotted results of his experiments, the Author finds that the total apparent compression c, is for wrought iron,

$$c = \frac{\delta^3}{1{,}150}\left[1 - 1 \cdot 3\,\frac{D}{\delta} + 0 \cdot 42\left(\frac{D}{\delta}\right)^2\right]$$

in millimètres (0·039 inch), when D is the diameter of the punch and δ the thickness of the plate. It follows from this formula that $c = 0$ for $\frac{D}{\delta} = 1 \cdot 54$; in other words, there is no compression when $D > 1 \cdot 54\,\delta$; but in this case shearing commences at once.

The second part of the Paper is devoted to a consideration of the work done in punching, and the Author deduces the result; that the work done, a, is in kilogrammes per square millimètre (0·635 ton per sq. inch) of the cylindrical surface of the hole,

$$a = 0 \cdot 04\,\delta\left[1 - 0 \cdot 21\left(\frac{D}{\delta}\right)^2\right] \text{ for } \frac{D}{\delta} < 1 \cdot 54,$$

and

$$a = 0 \cdot 02\,\delta \qquad \text{for } \frac{D}{\delta} > 1 \cdot 54.$$

This result agrees very satisfactorily with Hartig's empirical formula,

$$a = 0{\cdot}25 + 0{\cdot}0145\ \delta.$$

The Paper is accompanied by drawings prepared from photographs of the etched test pieces.

W. P.

Results of Experiments on Deflection made on Iron and Steel Rails by Strains Exceeding the Limit of Elasticity and Approaching Rupture. By H. Tresca, Hon. M. Inst. C.E.

(Memoires de la Société des Ingénieurs civils, vol. xxxii., p. 1123.)

The laws relating to the flexure of solids, such as iron and steel beams centrally loaded, have been sufficiently confirmed by experiment up to the limit of their elasticity; but at present only insufficient indications have been obtained of the state in which permanent flexure leaves the material with respect to the new mechanical properties it may have acquired. In what sense its coefficient of elasticity is varied, whether the limit remains unchanged or is extended, and to what extent the conditions determining rupture are modified, are as yet insufficiently ascertained.

Taking advantage of the opportunity offered for investigating these questions while making some experiments for the late General Morin on iron and steel rails, M. Tresca so arranged them as to obtain the necessary data. He had placed at his disposition seven rails, three of iron and four of steel, and of different makes and sections, furnished by the Chemin de fer du Nord, some being quite new, and others having been in use. They were—

VII. Steel rail from the works at Imphy, laid down 10th August, 1867, taken up 3rd April, 1868.
IV. „ from Terre-Noire, laid down 25th November, 1867, taken up 31st January, 1868.
V. „ from Terre-Noire, laid down 27th January, 1868, taken up 2nd April, 1868.
III. „ from Imphy, laid 10th August, 1867, and taken up 2nd April, 1868.
II. Iron rail from the works of M. de Wendel.
VI. „ „ Seraing, June 1867.
I. „ „ M. de Wendel.

These rails were placed horizontally under two resistances, either 16·4 feet or 10·18 feet apart, and the necessary pressure was exerted upwards at the centre by a hydraulic press. Lines were drawn at the centre and extremities of the rails, and the most minute deflections, either at the centre or the ends, observed by micrometer telescopes, the ends being very carefully observed in order to eliminate any error due to depression or compression of

supports. Each rail was repeatedly pressed and relieved at varying intervals, during which numerous observations were made. The profiles and sections were accurately determined, and the moments of inertia obtained by the graphic method. Tables and curves showing the deflection under different loads, and the variation in the deflection under different loads after subjection to strains within and above the elastic limit are given. For each rail the coefficient or modulus of elasticity is calculated for the deflections within the limit of elasticity first observed, and this is compared with that of deflections observed after the molecular change induced by continued strain under increased loads, the strain per unit of section under the determinant deflections being also given.

Generally the experiments, and the numerical deductions therefrom, confirm the received laws relating to deflection of beams or girders of iron and steel with respect to the position of the neutral axis, the period of elastic flexure, the direct proportion of the deflection to load, and its proportionality to the cube of the length or span. They show that for the two metals of commercial qualities the modulus or coefficient of elasticity E is nearly the same, and is represented by $E = 21 \times 10^9$ per square mètre, or 29,806,451 per square inch, a fact supported by M. Tresca's previous experiments on Swedish irons and cementation steel made from the same irons.

These experiments, however, demonstrate that the limit of elasticity is extended, for any bar, in proportion as it has been previously submitted to heavier strains, as shown by increasing permanent deflections; and that by bringing the molecular elasticity repeatedly into play, the limit of elasticity may be caused to approach the point of rupture, and yet the coefficient of elasticity be but slightly affected; but there is always a diminution (which diminution may be as much as $\frac{1}{10}$) from the original coefficient. It is claimed for these experiments to show that iron and steel as they leave the works are in a state of instability which can only be removed by use. When subjected to use they become, in consequence of strains brought to bear upon them, more homogeneous and more elastic, but at the same time more flexible.

W. W. B.

The Use of Steel for Bridges. By T. Cooper.

(Transactions of the American Society of Civil Engineers, vol. viii., p. 263.)

American bridges, the Author states, are generally built up of the following members:—

1. Chord and web eye-bars; round, square, or flat bars, with a forged head at each end.

2. Lateral, diagonal, and counter-rods of a lighter section than the above, sometimes with a forged eye at each end, and an intermediate screw adjustment, and sometimes with the end simply upset for a screw thread.

3. Floor beam hangers; generally bent hoops with screws, threads cut upon the upset ends.
4. Pins; as accurately turned as engine work in this country.
5. Lateral struts; 6. Posts; and, 7. Top chord sections, all formed by riveting together plates, angles, channels or special sections, some square-ended, others pin-connected.
8. Floor beams and stringers of rolled beams, plate, or trussed girders.

The Author practically accepts the English Admiralty specification for steel plates, &c., but for the smaller bars would require a greater tensile strength with the same ductility. He points out that steel will probably necessitate a change in the details of American bridge work, and even admits that riveting might be better than pin-connections, as conducing to a more uniform distribution of the strain. His final conclusion is, that "there will be no economy in the exclusive use of steel in spans of ordinary sizes (single-track bridges, up to 150 or 175 feet), as long as steel is dearer than iron."

In the course of the discussion, Mr. T. C. Clarke, M. Inst. C.E., read a letter from the engineer of the Rhenish railways, in which it was stated that, "The recent experience of Dutch engineers, in regard to the use of steel in bridge building, has led to its entire abandonment in Holland," because some riveted cross-girders, when tested, gave way under about ⅓ of the calculated breaking-weight. Mr. Clarke's comment upon this is, that "No maker of steel has yet been able to overcome the danger of steel suddenly giving way when nicked or cut into."

Speaking of steel eye-bars, Mr. O. Chanute remarks that "It is understood the modulus of elasticity varies greatly, say from 25,000,000 to 35,000,000 lbs., or a range of 40 per cent. The steel used for the boilers on Mr. Chanute's line—the Erie railway—is singularly mild, averaging little over 23 tons per square inch, and is characterised as substantially weldless iron of soft quality. In the case of bridge work, he requires that contractors should furnish evidence of its suitability to the intended purpose, without specifying any distinct tests.

B. B.

Road and Railway Bridges over the Elbe, at Riesa.

By Finanzrath Köpcke.

(Mittheilungen des Sächischen Ingenieur- und Architekten-Vereins, 1879, p. 12.)

A road bridge, and a bridge carrying the lines of the Leipzic and Dresden railway are placed side by side, about 100 feet higher up the river than an older work, which was destroyed by a flood in 1876. The bridges have separate main girders, but have their piers and abutments in common, and are similar in spans,

depth of girders, and general outward appearance. Each bridge has four spans, three of 332 feet and one span of 144 feet. The girders have parabolic compression booms, the longer spans having a total depth of 49·2 feet, the shorter ones of 21·6 feet. As in the Boyne bridge and others, light diagonal bracing is used between the booms without any verticals, the braces having thus the double function of transmitting the loading to the top boom, and of taking up the shear during the passage of any moving load over the bridge. The braces are riveted together where they cross.

The dimensions of the different members have been calculated for a stress of 5·6 tons per square inch in the ironwork of the railway bridge, and of 6·83 tons per square inch in that of the road bridge. The maximum load caused a deflection of 1·28 inch in the long span of the railway bridge, of which 0·08 inch was permanent set. The deflection of the road bridge was only 0·28 inch when fully loaded.

The two special features which the Author has introduced into the bridge are: (i.) The mode of working in the intermediate longitudinals; and (ii.) The combination of arch and girder form in roadway bridges. As to the first of these, Herr Köpcke makes the longitudinals continuous through the cross-platform girders (instead of carrying the latter through the longitudinals) throughout the whole length of the main girders, and plates right across a length of about 12 feet at each end, so as to form an excessively stiff cross girder, to which the longitudinals are firmly connected. By using this construction, the Author considers that he is entitled to assume that the longitudinal forms a part of the lower boom and shares its stresses; whereas in the common construction they only take the bending stresses due to a passing load, and cannot share the longitudinal stress in any way. In the result it was found that the total deflection of the railway bridge, when tested fully loaded, was 1·28 inch, of which 0·08 inch was permanent set. The test deflection of the road bridge was 0·28 inch.

The action of the longitudinals in aiding the lower booms of the main girders is incomplete when the bridge is only partially loaded. Under these circumstances the stress varies in different sections of the lower booms, being distributed through the braces, while the stress in the longitudinals must remain constant from end to end. By this cause the distribution of stress in the booms may be greatly altered, and under certain circumstances there may even be compression instead of tension in some of the bays. This can occur with ordinary loads only in the case of the road bridge, but both bridges have their lower members stiffened by horizontal diagonal bracing along their whole length.

The other special feature mentioned above occurs only in the road bridge, and consists in an arrangement (first proposed by the Author, in principle, in 1865) by which the bridge is made a sort of combination of arch and bowstring girder. This is effected by putting a constant thrust equal to about 600 tons upon one end of the main girders, the other end being stayed against this thrust

by wrought-iron braced struts, backed by a mass of masonry. The thrust is obtained by hanging a mass of slag brick, weighing about 300 tons, to one end of a knee lever (ratio 2 : 1) placed in a chamber built behind one abutment of the bridge. The knee lever is a built-up structure of wrought iron, and the thrust is transferred to the end of the girder by wrought-iron connecting rods. The thrust is transmitted through the whole range of girders, whose ends are arranged to bear against each other throughout, and each girder end has a roller bearing over each pier.

Details are given as to the weight which is believed to have been saved by this construction. The Paper is illustrated by one plate, showing the whole bridge upon a somewhat small scale.

A. B. W. K.

Continuous Girder Bridge over the Szamos (North-Eastern Railway of Hungary). By A. Meiszner.

(Allgemeine Bauzeitung, 1879, pp. 43 and 49.)

This bridge takes the place of an old wooden one of 525 feet long (in five spans), and has been erected parallel to it, and at a distance of about 40 feet. It has four openings, two of 124·4 feet, and two of 155·1 feet (the latter being the two middle openings), the four sets of girders being connected over the mid-stream piers so as to form a continuous girder of 559 feet span. The bracing is a quadruple lattice work, the booms being parallel throughout and of a depth (19 feet) sufficient to allow of cross bracing being carried between the upper booms as well as between the lower ones. The bridge is for a single line only.

The assumptions made in the calculations connected with the bridge were as follow:—For main girders, a maximum moving load equal to 1·2 ton per lineal foot; for platform girders, the axle loads of a locomotive weighing, with its tender, 66 tons. The intensity of stress in the main girders was taken not to exceed 11,400 lbs. per square inch net section; in platform girders to be not more than 10,400 lbs. per square inch; in rivets, not more than 8,500 lbs. per square inch; in verticals over piers not more than 6,400 lbs. per square inch; and the pressure on abutments not to exceed 355 lbs. per square inch.

Besides these preliminaries, the Author's first Paper gives the equations for the bending moments over the points of support, and the value of these moments for different conditions of loading. The plates which accompany it are very detailed, and contain the following: (i.) General view of bridge; (ii.) Details of masonry of piers and abutments and of foundations and cofferdams; (iii.) Diagrams of maximum bending moment and shear; (iv.) Details of sections of booms and braces, and of manner of connecting them; (v.) Details of fixed and roller bearings; (vi.) Details of

expansion chair for rails; and (vii.) Details of timber staging, &c., used in erecting the bridge.

The second Paper commences by giving in great detail the calculations of the dimensions of all the principal parts, including platform girders and wind bracing, and the details of the riveted joints. The stress diagrams (having the special interest that they are for a continuous four-span girder) are also described, and the method of determining the dimensions of the roller bearings is given.

The Paper concludes with particulars of the tests, weight, and cost, of which the following is a summary:—The deflections under a load of 1·24 ton per lineal foot, after it had been standing for an hour on each span successively, were 0·5, 0·87, 0·88, and 0·63 inch respectively; and after a similar application of a load equal to 1·37 ton per lineal foot they were 0·71, 1·08, 1·06, and 0·71 inch respectively. Two locomotives with their tenders (each weighing 66 tons) were placed front to front and run across the bridge at a rate of 23·6 miles per hour, and the side swing of the bridge was found to be 0·12, 0·12, 0·10, and 0·9 inch in the four spans respectively; while the permanent (vertical) deflection caused by this load was 0·04, 0·06, 0·04, and 0·04 inch. The principal weights were:—

Booms	274 lbs. per lineal foot.	
Braces	172 „	
Wind bracing and end verticals . .	125 „	
Total for main girders .	571 lbs.	= 5·01 cwt. per lineal foot.
Platform girders, &c.	245 lbs.	
Total wrought-iron work	816 lbs.	= 7·28 „ „

This corresponds to a total weight of 204 tons, which, with the weight of the fixed and movable bearings and plates and all other ironwork (not including rails and chairs), makes the total weight of ironwork in the bridge 220 tons, or nearly 8 cwt. per lineal foot, the bridge being, it will be remembered, for a single line only. Details of the cost of the bridge are also given, from which it appears that its total cost (including preliminary expenses) was just over £13,000.

A. B. W. K.

The Erdre Viaduct. By M. Dupuy.

(Annales des Ponts et Chaussées, 5th series, vol. xvii., p. 331.)

This viaduct was built for carrying the Nantes and Châteaubriant Railway across the river Erdre. It consists of three semicircular masonry arches, having spans of 26 feet 3 inches, and resting on piers 5 feet 7 inches wide, and abutments 30 feet 8 inches long, on each bank, and a central wrought-iron arch

crossing the river with a single span of 311 feet 8 inches. The soft nature of the river bed, extending down to a depth of 69 feet below low-water level, rendered this large span necessary; whereas hard rock crops up at the surface on each bank. The wrought-iron arch is composed of four ribs, having a rise of 39 feet 7 inches, and spaced 7 feet 2½ inches from centre to centre. Each of these ribs is 7 feet 2½ inches deep at the crown, and 8 feet 2½ inches near the abutments. The tympana consist of vertical wrought-iron beams, made of plates and angle-irons, 2 feet 5½ inches wide, with spaces of 7 feet 7 inches between them. Straight longitudinal girders, 3 feet 1½ inch high for the outer arches, and 1 foot 4 inches high for the inner arches, support a double line of rails on the platform of the bridge, which consists of a plate-iron flooring covered with a layer of ballast 1 foot 7 inches thick. Each arched rib is composed of flanges 1 foot 11½ inches wide, both at the intrados and extrados, made of four layers of ½-inch plates, and joined to a solid web plate, $\frac{7}{16}$ inch thick, by angle-irons 4 inches × 4 inches × ½ inch. A stiffening plate, ⅜ inch thick, extending as far out as the flanges, is fixed all along the centre of the web of the arched ribs by angle-irons 3½ inches × 3½ inches × $\frac{7}{16}$ inch. Plate-iron stiffeners, moreover, $\frac{5}{16}$ inch thick, arranged radially to the intrados, and corresponding to the tympana, give rigidity to the arched ribs, being fastened to their webs by angle-irons 3 inches × 3 inches × ⅜ inch. The arched ribs are also braced, at top and bottom, perpendicularly to their webs, by angle-irons and plates, and are cross-braced by T irons. The upper and lower flanges of the arched ribs are brought together at the springings, and concentrate the pressures at each end on a steel bar 8 inches in diameter. Wedges were inserted to tighten up the arch after the removal of the centres, when the whole weight rested on the steel pivots. The centres for erecting the arch were supported on twelve rows of piles driven into the soft river bed.

A summary of the weights and prices of the different materials of which the arch is composed is given in the following Table:—

Material.	Weight.	Price per Ton.			Total Cost.
	Tons.	£.	s.	d.	£.
Wrought iron	906	19	18	3	18,038
Cast iron	38¼	13	6	4	528
Steel	18·8	40	12	9	764
Lead	3·3	26	8	4	87
					19,417
Other expenses					1,383
Cost of the arch					£20,800

The construction of the arch occupied twenty-one months; and the total cost of the whole of the viaduct amounted to £33,200.

The Author gives in detail the various calculations made in designing the arch, which are based on the formulæ of Messrs. Bresse and Collignon. The maximum calculated strain would

occur at the sixth upright, when the test rolling load of 1 ton per lineal foot for each line of way is distributed over only three-fourths of the bridge, and would amount to 4¼ tons per square inch; but with the load distributed all along the bridge the greatest strain would only amount to 3⅓ tons, and would occur at the fourth upright from the abutment. It is assumed that the arch rests entirely on its pivots, and this is correct as regards the permanent load at the mean temperature, as the wedges only come into play to prevent deflections.

The centres having been removed when the temperature was 61°, the variations from this temperature will not exceed 54°, which would give 9½ tons as a maximum increase in the thrust on the abutments from this cause.

The bridge was subjected, on completion, to a series of tests, and its deflections under the various loads are shown graphically on the drawings accompanying the article. The lateral oscillations, produced by the rapid passage of trains, amounted only to $\frac{1}{10}$ inch; and the tests show that the deflection at the crown of the arch can never exceed ½ inch, that the longitudinal displacement will always be under $\frac{1}{10}$ inch, and that the ribs are rigidly connected. The wedges tend to distribute the pressure of the loads, and consequently the strains, uniformly; and, from the results obtained by means of the apparatus for measuring strains,[1] it appears that the maximum estimated strain is nowhere and in no case exceeded, and that consequently the structure is stronger than its calculated strength.

L. V. H.

Tunnels on the Railway from Mende to Sévérac.

By M. Séjourné.

(Annales des Ponts et Chaussées, 5th series, vol. xviii., p. 371.)

The object of the article is to show how the cost of construction of four tunnels, for a single line, on the railway from Mende to Sévérac, was estimated; and to what extent these estimates have been verified by the contract prices for the tunnels, three of which are in course of construction.

The section consists of a semi-ellipse, 13 feet 1 inch high and 16 feet 5 inches across, supported by two side walls with faces forming arcs of a circle of 27 feet 8 inches radius. The level of the rails is 6 feet 7 inches below the springing of the arch, so that the top of the tunnel is 19 feet 8 inches above the rails. The drainage is effected by a rectangular masonry culvert (1 foot × 1¼ foot) placed at the side where there is most water. The tunnel

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lii., p. 296.

being in rock, its roof is merely lined with radiating courses of masonry, 1 foot 4 inches thick, and the side walls are built, against the rock, of ordinary masonry of the same thickness. A space of at least 4 inches between the rock and the roof is filled with a layer of dry stones, and the water escapes through outlets made in the arch, $3\frac{1}{4}$ feet above the springing. Where any thrust has to be borne by the lining of the tunnel, the thickness is increased to 2 feet or 2 feet 8 inches; but for the most part the thickness of 1 foot 4 inches has sufficed.

The estimates apply only to tunnels in hard rock, driven from each end. As trial headings were driven in the tunnels before contracts were made, the price, Π, per cubic yard of excavation for these headings was ascertained, and the price, P, per cubic yard of excavation in open cutting in the same material was known, from which the price, π, per cubic yard of excavation for the whole tunnel could be deduced. The proportion $\frac{\pi}{\Pi}$ for similar tunnels of less height was ascertained to be 0·496, so that with a larger section the proportion should be somewhat less. Adapting Hr. Nordling's formula for obtaining the value of π in terms of P, to the circumstances of the case under consideration, it appears that $\pi = 5$ P. Allowing $\frac{1}{15}$ for incidental expenses, and $\frac{1}{10}$ for profit, the price for the small heading is $\Pi = 10 \cdot 6$ P. Whence $\frac{\pi}{\Pi} = \frac{5}{10 \cdot 6} = 0 \cdot 47$. The actual price Π in the trial headings for the four tunnels was between 9·27 P and 11·3 P. The various results obtained with respect to these tunnels are given in the following Table:—

Name of Tunnel.	Length.	Cost per Lineal Yard for a Sectional Area of 42·24 Square Yds. X.			Cost per Cubic Yard of Excavation in Heading, Sectional Area, 8·37 Square Yards, Π.			Cost per Cubic Yard of Excavation π.		$\frac{\pi}{\Pi}$.	Cost per Cubic Yard of Excavation in Open Cutting of similar material P.		$\frac{\pi}{P}$.	Nature of Material.
	Yds.	£.	s.	d.	£.	s.	d.	s.	d.		s.	d.		
La Farelle	383	21	1	10	1	2	9	10	0	0·44	2	0	5·00	Fucoidian and dolomitic limestone.
Beodejeu	165	20	17	2	1	2	6	9	10	0·44	2	0	4·95	Fucoidian limestone.
Les Achatis	129	22	8	5	1	0	7	10	6	0·51	1	10	5·70	Schist and gneiss.
La Rouvière	384	31	1	9	1	8	4	14	6	0·50	3	1	4 76	Crystalline gneiss.

When a trial heading has been driven so that Π is known, the equation $\pi = 0 \cdot 48\ \Pi$ gives the value of π. If no trial heading has

been made, the value of π may be obtained from the equation $\pi = 5$ P; where P is the price of a cubic yard of excavation in a deep cutting through the same kind of material; and for the type of tunnel already described, the cost per lineal yard X = 211 P. In the Author's opinion the height of 19 feet 8 inches might be reduced to 17 feet 1 inch for short single-line tunnels, without inconvenience as regards ventilation.

The Author then proceeds to discuss the advisability of making a tunnel suitable for two lines of way, leaving some excavation at one side, and a portion of one of the side walls unfinished, till a second line is required, in preference to building a single-line tunnel 19 feet 8 inches high. He shows that the increase in cost would be only 11 per cent. for tunnels made without shafts; and he considers that, in such cases, when the land and bridges are provided for a double line, the tunnels ought also, for similar reasons, to be built so as to be easily completed for a double line of way when necessary.

L. V. H.

An Instrument for Gauging the Flow of Streams.

By M. de Perrodil.

(Annales des Ponts et Chaussées, 5th series, vol. xiii., p. 467, 1 pl., and vol. xix., p. 11, 1 pl.)

This instrument, which is called a hydro-dynamometer, measures the velocity of a current by means of the torsion produced on a wire by the pressure of the water against a disk fastened to the end of the wire.

A narrow frame, resembling in form the longitudinal section of a tube terminating in a bulb at the top, is immersed vertically in the water, and turns, near its upper extremity, on a vertical pivot at the end of a horizontal bar which encircles, at its other end, an upright pole driven into the bed of the stream. A little, short, hollow cylinder, fastened to the under-side of the bar exactly below the pivot, receives the end of the vertical wire, which can be secured by a screw. The wire, which is situated in the axis of the frame, passes through the centre of a horizontal graduated circle, fastened, above the water-level, across the widest part of the frame, and is secured to the bottom cross-stay of the frame. A needle, fastened to the wire just above the graduated circle, serves to measure the torsion of the wire. A disk, placed in the same plane as the frame, projects from the end of a horizontal arm fastened to the bottom of the frame.

The instrument having been fixed with the disk at the desired depth, and on the up-stream side of the post, the disk assumes a

position parallel to the current between the frame and the post, the needle and the frame are in the same plane, and the needle at the zero of the circle. On turning the needle by hand a torsion is produced on the wire, and the frame and disk may be thus made to assume a position perpendicular to the current. As the needle oscillates inconveniently, owing to variations in the velocity of the current, the wire is secured at the top by the screw as soon as the frame and disk are exactly perpendicular to the current, and the needle being fixed, the observer is free to note the oscillations of the graduated circle, and can read off the mean angle of torsion, which is independent of friction.

The velocity of the current is obtained by the equation $v = c\sqrt{a}$; where a is the angle of torsion, and the value of c can be determined, either approximately from the coefficient of torsion of the material, or actually by experiment. The Author determined by experiment the values of c for the three different-sized disks he employed. The instrument was placed under one end of a small footbridge revolving round a central axis, and it moved in an annular trough, 2 feet wide, containing water. By turning the footbridge, any desired velocity could be imparted to the instrument, and the motion was so regulated as to keep the angle of torsion constant. The motion imparted to the water by the instrument passing through it was also observed, so that the actual velocity of the instrument through the water might be accurately ascertained.

A brass wire, 6½ feet long and ⅛ inch in diameter, was employed. A disk with a radius of 2½ inches was used for velocities not exceeding 1 foot 4 inches per second, with a radius of 1¼ inch for velocities between 1⅓ and 3¼ feet per second, and with a radius of ⅝ inch for velocities between 3¼ and 10 feet per second. The distances in these three cases between the centre of the wire and the centre of the disk were respectively 8 inches, 4 inches, and 2 inches. The Author considers Woltmann's hydrometric mill inferior to his instrument, as errors may occur in registering the number of turns of the mill, and also in marking the time, and as it has to be drawn out of the water to be read. Also the true equation for deducing the velocity from the results of observations with Woltmann's mill has not been thoroughly agreed upon, M. Chasles considering it to be an equation to a straight line, and Herr Baumgarten an equation to a parabola; but experiments conducted by the Author, and recorded in the last article, confirm the correctness of M. Chasles's view. A superiority is claimed for the instrument over Pitot's tube, on account of its indicating the mean velocity with greater accuracy. Moreover, the instrument actually employed can indicate a velocity of ⅜ inch per second; whereas Woltmann's mill ceases to revolve in a current whose velocity is reduced to 4 inches per second, and a Pitot's tube is even less suited to measure accurately low velocities.

L. V. H.

Channel of Constant Mean Velocity. By E. Gramatzky.

(Professional Papers on Indian Engineering, Roorkee, 2nd series, vol. iv., p. 405.)

This is a note on a Paper by F. E. Rose, at page 211 of the same volume, an abstract of which appeared in the Minutes of Proceedings, vol. xliii., p. 348. The Author states that the Paper by Mr. Rose professes to solve the following problem. To calculate such a contour for the cross section of a channel that for all depths (x) of water running in it with a given declivity (p), the mean velocity (v) of the current shall be constant and equal to a given quantity. He then proceeds to show that if the fundamental equation $v = n\sqrt{p\frac{s}{c}}$, and the expression obtained for the hydraulic mean depth $\frac{s}{c} = \beta\frac{\phi}{1+\phi}$, where $\beta = \frac{v^2}{n^2 p}$, are both true; then $1 = \frac{\phi}{1+\phi}$, or $1 = 0$.

Again, the area s and the perimeter c are not independent, but c is a function of s, say $c = f(s)$; thus $\frac{v^2}{n^2 p}\cdot f(s) = s$; but v, n (the coefficient of discharge), and p are all constants, therefore if s is diminished without limit, $f(s)$ becomes zero when s is zero; but the area and its perimeter can only vanish simultaneously when x and y become zero simultaneously.

From the equation—

$$d\,x = \frac{v^2}{n^2 p}\cdot\frac{d\,y}{\sqrt{y^2 - \frac{v^4}{n^4 p^2}}},\text{[1]}$$

by integrating without assigning limits is obtained

$$x = \frac{v^2}{n^2 p}\,\text{hyp.}\log\left\{y + \sqrt{y^2 - \frac{v^4}{n^4 p^2}}\right\} + \text{C},$$

and to get the value of the constant C put $x = o$ and $y = o$, then

$$x = \frac{v^2}{n^2 p}\cdot\text{hyp.}\log\left\{\frac{y + \sqrt{y^2 - \frac{v^4}{n^4 p^2}}}{\frac{v^2}{n^2 p}\sqrt{-1}}\right\} \quad . \quad . \quad (1)$$

where x is imaginary for every real value of y except zero.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 348.

A note by Captain Allan Cunningham follows, in which he points out some misprints in Mr. Rose's Paper. One of these occurs also in the abstract at page 349, last line but one, where $-\log.^{-1} a x$ should read $+\log.^{-1} a x$. He also suggests that it would be better to use the exponential form $\epsilon^{\frac{x}{\beta}}$ instead of $\log.^{-1} a x$; then

$$y = \frac{\beta}{2}\left(\epsilon^{\frac{x}{\beta}} + \epsilon^{-\frac{x}{\beta}}\right), \text{ the equation to the common catenary,}$$

area $$s = \beta^2\left(\epsilon^{\frac{x}{\beta}} - \epsilon^{-\frac{x}{\beta}}\right),$$

perimeter $$c = \beta\left(\epsilon^{\frac{x}{\beta}} - \epsilon^{-\frac{x}{\beta}} + 2\right),$$

$$\beta = \frac{v^2}{n^2 p} = \frac{s}{c} = \beta \cdot \frac{\epsilon^{\frac{x}{\beta}} - \epsilon^{-\frac{x}{\beta}}}{\epsilon^{\frac{x}{\beta}} - \epsilon^{-\frac{x}{\beta}} + 2}, \text{ therefore}$$

$$1 = \frac{\epsilon^{\frac{x}{\beta}} - \epsilon^{-\frac{x}{\beta}}}{\epsilon^{\frac{x}{\beta}} - \epsilon^{-\frac{x}{\beta}} + 2},$$

and this is approximately true only when x is very large compared with β, so that $\epsilon^{-\frac{x}{\beta}}$ is very small.

It is further pointed out by Captain Cunningham that Mr. Gramatzky's conclusion from equation (1), that no curve can possess the required property, is not warranted by the investigation given, owing to the way in which the constant C is determined; and that all that can be fairly said to be proved is, that no one single continuous curve can possess the required property.

F. T.

Channel of Constant Mean Velocity.

By Capt. A. Cunningham, R.E.

(Professional Papers on Indian Engineering, Roorkee, 2nd series, vol. vii., p. 307.)

The Author adopts, as a sort of rough approximation only, the formula $U = C\sqrt{rI}$ ... (1), where I is usually understood to be the average slope of the bed, and is therefore a constant at any

one place in the same channel. C, however, is a variable depending on many elements, the chief of which is perhaps the "rugosity" of the channel. Bazin has proposed the formula $C = \sqrt{1 \div \left(a + \frac{\beta}{r}\right)}$, where a and β are numerical quantities depending on the rugosity of the channel. Kutter has given the coefficient $C = \dfrac{m + 1 \div f}{a + \dfrac{m f}{\sqrt{r}}}$, where $m = \beta + \frac{\gamma}{I}$ and a, β, and γ are constant numerical coefficients, the same for all channels, and f is a quantity depending on the rugosity of the channel. Thus, even taking these new values for C, the only variable in the expression $C \sqrt{r\,I}$, for the same place in the same channel is r; therefore a channel of constant mean velocity for all depths at the same place must be a channel of constant hydraulic mean depth. The Author admits that this argument is imperfect, as the formula (1) is only an approximation.

Thus, in the channel sought for, the area of the curve must vary as the length of the arc; and moreover, the area and arc must be comprised within the same limits, and the curve of the wetted border must be continuous between those limits. But there is no curve which will satisfy all these conditions. The contour given by Mr. Rose's equations was a pair of half catenaries, with a straight portion $2\,\beta$ and curves l[1], but the area of this varies as l, instead of as $(\beta + l)$. When, however, β is very small compared with x, then this contour approximately satisfies the required conditions, and the curve approaches in form the logarithmic curve $y = \frac{\beta}{2}\,\epsilon^{\frac{x}{\beta}}$, the surface width increasing very rapidly as the depth increases. An approximate solution would also be obtained if the horizontal bottom of the channel consisted of a material opposing much less resistance to the current than the material of the banks. Lastly, a rectangular section of great depth compared with its width will also satisfy approximately the required conditions.

F. T.

On the Action of Falling Water. By J. S. Beresford.

(Professional Papers on Indian Engineering, Roorkee, No. cccxxii., vol. ix.)

It having been proposed to erect a masonry weir at Keroni, on the Ken river, with an exceptionally great drop, questions arose as

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 350.

to the amount of pressure to which the rock foundation of the weir would be subjected by the action of the falling water. This Paper contains a theoretical discussion of the action of a falling stream of water by Mr. Beresford, Mr. Eliot, Captain Cunningham, and Professor Unwin, and an account of some very interesting experiments bearing on the question.

The face of the proposed weir is nearly vertical, and in flood there will be a fall at the weir of 16·5 feet, with a depth of water in the river below the weir of 65 feet. In low conditions of the river there will be a fall at the weir exceeding 60 feet, with a depth of water over the natural rock apron not exceeding 8 feet.

The questions raised in regard to the action of the water were, whether it was of the nature of a ramming action like the fall of a solid mass, or whether it was a steady fluid pressure to be determined by hydrodynamic principles. Next, what was the whole amount and distribution of the pressure due to the falling water on the rock below the weir, and especially what was the maximum intensity of the pressure. Mr. Beresford expressed the opinion that the greatest intensity of pressure could not exceed that due to a column of water of a height equal to the fall, while Mr. Eliot and Captain Cunningham inclined to think that the maximum pressure intensity might be two or three times that amount. The experiments clearly show that Mr. Beresford was right.

The experiments were made in this way. Brass mouth-pieces were fitted in the bottom of a barrel, supplied with water so as to form jets falling vertically, and about $\frac{1}{2}$ inch to 2 inches diameter, under heads of from 26 to 43 inches. These jets impinged normally on a smooth brass plate, 9 inches diameter. From a hole in the brass plate communication was made to a pressure column which balanced the pressure at the mouth of the hole. By shifting the plate horizontally, the hole could be brought to the centre or to any other part of the jet. The pressures observed, when plotted, gave a curve of the distribution of pressure for the whole area acted on by the jet.

In no case did the intensity of pressure reach the pressure due to the height from the plate to the free surface of the water in the barrel, but in some cases it approached this limit within $\frac{1}{16}$ inch. The pressures were measured at from 10 to 36 points, between the centre of the jet and the point on the plate where the pressure became sensibly zero, and it was found that the pressure extended over an area on the plate about four times as great as the section of the jet. The following Table gives the pressures observed at intervals of $\frac{1}{20}$ inch from the axis of jet. Some further experiments are also given with a rectangular jet, and with a jet striking smaller plates of about the same section as the jet.

Experiment 1. Jet $\frac{13}{16}$ Inch Diameter.			Experiment 2. Jet $\frac{13}{16}$ Inch Diameter.			Experiment 3. Jet $1\frac{13}{16}$ Inch Diameter.		
Height from Free Surface to Brass Plate, in Inches.	Distance from Axis of Jet in 20ths of an Inch.	Pressure in Inches of Water.	Height from Free Surface to Brass Plate, in Inches.	Distance from Axis of Jet in 20ths of an Inch.	Pressure in Inches of Water.	Height from Free Surface to Brass Plate, in Inches.	Distance from Axis of Jet in 20ths of an Inch.	Pressure in Inches of Water.
43	0	40½	42¼	0	42	27⅛	0	26⅞
"	1	39–40	"	1	41⅞	"	1½	26⅞
"	2	37½–39½	"	2	41½–41⅝	"	2½	26⅝
"	3	35	"	3	41	"	3½	26½–26⅝
"	4	33½–37	"	4	40½–40⅜	"	4½	26⅜–26½
"	5	31	"	5	39⅜	"	5½	26½–26⅞
"	6	21–27	"	6	37½	27	6½	26⅛
"	7	21	"	7	34½	"	7½	25⅞
"	8	14	"	9	27	"	8½	25½
"	9	8	42½	10	23	"	9½	25
"	10	3½	"	11	18½	"	10½	24½
"	11	1	"	12	13	"	11½	24
"	12	½	"	13	8½	"	12½	23¼
"	13	0	"	14	5	"	13½	22½
			"	15	3	"	14½	21¾
			"	16	2⅛	"	15½	21
			42¼	17	1⅝	"	16½	20½
			"	19	1	"	17½	19½
						"	18½	18
						"	19½	17
						26½	22½	13½
						"	23½	12½
						"	24½	10¾
						"	25½	9½
						"	26½	8
						"	27½	7
						"	28½	6¼
						"	29½	5
						"	30½	4½
						"	40½	4
						"	41½	3½
						"	47	2

W. C. U.

On the Employment of Curved Concentric Laminæ to Charge Siphons Alternately by Means of an Oscillating Liquid Column. By A. Caligny.

(Comptes rendus de l'Académie des Sciences, vol. xc., p. 119.)

The Author has previously used such plates to diminish the resistance opposed to the flow of water in sharp "elbows," and it can easily be understood, that in the case of siphons of large

section, the effect of the difference in height of the water at the top and bottom of the section will cause an accumulation of air which will impede the flow of water; this can be overcome, as the Author has noticed in experiments made with a different object, by the introduction of curved concentric laminæ in the siphon, preferably of rectangular section, at its summit, and will oftener be easier than decreasing the height of the section and proportionately increasing its breadth; the air, as the experiments proved, being driven with great regularity between the laminæ.

F. J.

The Amoo Daria, and the Possibility of Diverting it into the Caspian Sea. By N. G. PETRUSEVITCH.

(Zapiski Imperatorskava Tekhnitcheskavo Obstchestra 1879 Tekhnitcheskia Besedy, p. 125.)

The Author opens his Paper by allusions to the universal importance of the Suez Canal, Panama, and Sahara projects, and the more immediate interest that Russia has in the subject of his communication.

The first mention of the Amoo Daria is by Herodotus, 1000 B.C., who states that it flows by one channel into the Caspian Sea. In the first century Strabo speaks of two outlets, one into the Caspian, the other into the Sea of Aral. In the fourth century "Arian" and others speak of its flowing only into the Caspian; whilst from 920 to the fourteenth century Mussulman writers refer to its running into the Sea of Aral.

At present this river, rising in the Hindoo Kush, flows north-west into the Sea of Aral; its outlets were traced in 1819 by Mouravieff, the first Russian ambassador to Khiva, but the upper waters have only been explored in 1878. Its course is through a series of deserts, till Pituiaka, in the Khanate of Khiva, is reached; from thence to the Sea of Aral, into which it runs by three channels, the country is of a comparatively fertile character. The Sea of Aral is 243 feet above the level of the Caspian.

After dealing with the geography and government of the neighbourhood, he refers to the old channels. Of these, four have been discovered:—

(1). The Ungoos, running south from Tchardi.

(2). The Arta Kooyou, beginning at Hazar Asp, running south of Khiva.

(3). Beginning at the town of Hankee, is called Deudau.

(4). The fourth and most apparent begins at Nova Oorgeutsch, passes through the lake Sarakamisch, is traceable for 350 versts south to the Igdy well, then west through the Balkan range into the Caspian Sea. South of this channel is another, which, running in a parallel line, joined the above-mentioned course at the Igdy well.

It has been found that the Sea of Aral is gradually deepening towards the north, and this tendency has through time caused the Amoo Daria to change its original direction. The land rises from the Caspian to the Hindoo Kush, looking from north-west to south-east, and from a line so drawn falls to the north.

In considering the volume of water in the Amoo Daria, its velocity, and the possibility of diverting part of it, it is found that the river varies in width from ½ verst to 5 versts, and its velocity accordingly from 7 to 2 feet per second. It passes at the commencement of the delta 350 cubic sagiens per second (about the same as the Volga at Samara), and there are no reasons for all this body of water being required. It carries a great body of silt, from 0·002 to 0·0015 of deposit, or $\frac{1}{700}$ to $\frac{1}{800}$ of its capacity; the percentage in the Neva being 0·000054: and the quantity of salt in the river is very great. In 1878 the river was navigated for 800 versts above the Petro Alexandrovsky fortress to the frontiers of Afghanistan.

To deal with the old channel, No. 4.

From Novo Urgeutsch to the lake Sarakamish is 400 versts; to within 50 versts of this lake the fall is normal, viz., as the fall between the Aral and Caspian seas; but for these 50 versts the descent is very rapid, and the level of the lake is 49 feet below that of the Caspian. Dealing with the quantity of water near Khiva, necessary for the cultivation of the oasis, and the quantity flowing through the three mouths of the river, it is found that the central channel takes 51 per cent., the other two only 7 per cent. each; and 35 per cent. is lost by evaporation and for irrigation. To obviate interference with its value for navigation one of the mouths would have to be regulated, and only half the volume now passing would suffice.

The Sarakamish lake is intensely salt; it contains 8½ per cent. as compared to the ocean's 3½ per cent.

From Novo Urgeutsch by the old channel, through this lake and the Igdy well to the Caspian, is a distance of 900 versts; and he would propose a canal 210 feet broad by 7 feet deep. The difficulty is to inundate a basin of 10,000 square versts area, but with such a volume as might be diverted by opening from the river into the old channel, he concludes that the latter might be flooded, and that the water would find its way by the old course previously prepared for it into the Caspian Sea. As it is, when the river is high every year the level of the lake is raised 21 feet. The immense volume of water in the Amoo Daria permits of any amount of canalisation. The water should be taken from below the Khivan oasis, so as not to interfere with the only fertile vicinity, which is at present irrigated by dams, causing the water to flood the land.

Another course might be available from the Canal Shamrat, near the delta, which is 6 feet above the Aral and 249 feet above the Caspian; to traverse a distance of 800 versts the fall is ample.

The Sea of Aral is of little importance to Russia; surrounded

by sand, not a town, not a village on its shores. The northern part is frozen for six months in the year, and on the whole delta there are only 286 dessiatims under cultivation. At present, to send soldiers into Central Asia, from Orenburg to the Amoo Daria, they must march for 1,600 versts through sand.

An easy water communication such as that suggested is therefore most desirable.

W. M. C.

Diving Apparatus of the Elbe Regulation Administration.

By F. Bauer.

(Zeitschrift für Bauwesen, vol. xxix., p. 238.)

This apparatus was built in 1876, for removing rocks (graywacke) in the river Elbe, to a depth of 9 feet, and consists of an iron hull, 82 feet in length, 27 feet beam, 3 feet 3 inches height, 15⅝ inches draught. An opening in its centre line of 18 feet by 6 feet 10 inches admits a hollow-walled iron diving-bell, which is hung from a stout frame.

The interior of the bell consists of a lower chamber, 7 feet 10½ inches long by 4 feet 7¼ inches wide, and 7 feet 2⅝ inches high, on the top of which is placed the air lock, 4 feet 7¼ inches square, and 5 feet 11 inches high. The length on the outside is 12 feet; both ends are elliptical in shape. In lowering the bell, the spaces between the inside and outside shells are filled with water by a steam engine, which also furnishes the power for the air compressor and the lifting of the bell.

The cost of construction was—

	£
For the iron hull	515
„ wooden deck, frame, and sheds	110
„ bell, with chains, &c.	145
„ machinery and fittings	480
Total	1,250

In addition to the engineer and the diving master, only five labourers are required for the work on board and inside the diving bell. Inclusive of interest, renewal, and repairs, the cost of removing 1 cubic yard of stone has been 7*s.* 8*d.* to 9*s.* 2*d.* The apparatus was also in use for drawing old piles, at a cost of 7*s.* each.

F. R.

On Discharging from a Dredger Direct into Wagons.

By M. Gotteland.

(Annales des Ponts et Chaussées, 5th series, vol. xix., p. 29.)

The ordinary method of discharging excavation from a dredger into barges necessitates often a double shift, which is specially troublesome with wet and soft material, and also the employment of several barges. To remedy these inconveniences a plan has been adopted, in some dredging operations between Ambly and Belleray, of discharging the dredged material direct into wagons placed on a barge. The wagons run on rails laid along the bottom of the barge on transverse sleepers. The tramway rises at one end of the barge with an inclination of 1 in 6¼; and the bottom of the barge is also sloped up at the end, so as to rest on the slope of the bank. A movable section of permanent way, consisting of two rails, 7¼ feet long, connected by two flat transverse bars, unites the tramway on the shore with the tramway on the barge, being fastened to the fixed rails at each end by fish-plates, each pair of which are fastened by one pair of fish-bolts, and allow the rails a certain amount of play to accommodate the road to variations in level of the barge. The barge carries six wagons, each holding 1⅓ cubic yard of material. After the barge has been placed across the river, and secured by two stakes, and its position at the bank adjusted by ropes, and the movable portion of road fastened on, the wagons are removed by horses. A comparison of the cost of the two systems, which were both employed, indicates that a saving of 2*d.* per cubic yard, or on an average, one-fifth of the total cost, is obtained by discharging straight into wagons.

L. V. H.

Removal of Silt from the back of Reservoir Dams in Algeria.

By Martin Calmels.

(Annales Industrielles, 1879, December 21, col. 774, 1 pl., December 28, col. 806, and 1880, January 4, col. 26, January 18, col. 91.)

Some experiments were made last October, at the Sig reservoir, on the Author's method for removing silt from reservoirs by means of jets of compressed air. Full details are given of the apparatus employed, which consists essentially of a compressor, an accumulator, and a pipe for directing the jet. The accumulator is made of three galvanised plate-iron cylinders, each 6½ feet long, 13 inches in diameter, and nearly ¼ inch thick, and calculated to resist a pressure of 85 lbs. on the square inch. A pipe, 1 inch in diameter, conveyed the compressed air from the accumulator, over the reservoir dam and down the

other side, on to a double pontoon floating on the reservoir lake through the centre of which the tube of the air jet is directed as required. Two india-rubber tubes, each 50 feet long, serve to connect flexibly the iron pipe passing over the dam with a floating pipe, and the floating pipe with the jet. The nozzle at the end of the directing tube is conical, and has eight holes at the side $\frac{1}{10}$ inch in diameter. The rate of the current of air, under a pressure of 57 lbs. on the square inch, in a depth of water of 16 feet, would amount to 1,600 feet per second. With an 8 HP. engine, the jet can be worked continuously under a pressure of 5 or 6 atmospheres. Another jet with a single orifice, $\frac{1}{2}$ inch in diameter, has been made for working at a lower pressure. The action of the jet proved very satisfactory in stirring up the silt; and by opening the sluice-gates at intervals after working the jet in the deposit near the dam, a considerable quantity of silt was discharged with the water. As the silt, though sometimes forming a hard crust at the surface in dry weather, remains fluid below, the jet would gradually lower the deposit all over the reservoir by merely working near the dam, as the silt higher up would by degrees slide in and fill up the void made at the dam. The process, moreover, would serve not merely for keeping new reservoirs clear, but for removing accumulated masses of deposit from old reservoirs. By proper management, the Author considers that a large deposit might be gradually removed without interfering with the agricultural interests; and that by introducing the stirred-up silt, at suitable times, into the irrigation canals, it might be beneficial in fertilising the land. Also by removing the silt close to the dam, which frequently prevents the lifting of the sluice gates, the Author thinks a better system of gates might be adopted, which, by being contrived to open rapidly, would increase the scouring action at the sluices.

L. V. H.

McDonald's Fish-Way.

(Scientific American, Nov. 1, 1879, p. 275.)

The principle embodied in this fish-way—which has been adopted by the Board of Public Works of Virginia, and made an obligatory adjunct on all dams in that State—is the regulation of the flow in such a manner that, at whatever angle the way is placed, the velocity will be no greater at the bottom than at the top. The ordinary zigzags are dispensed with, the way being perfectly straight. In its simplest form it is a rectangular trough, 2 feet wide and 2 feet deep, inside dimensions. One end of the trough rests upon the crest of the dam, and is protected against the incursion of sticks, leaves, and other floating matter, by a V-shaped timber guard; the other end of the trough rests in the pool below, both extremities being firmly secured, and the struc-

ture supported at intermediate points if necessary. Transverse cleats, 3 inches high and 12 inches apart, are nailed to the bottom of the trough, and on these rest two stringers (1-inch boards, 10 or 12 inches high, set on edge), which divide the trough into three longitudinal compartments, of which the middle one is 12 inches wide, and each of the outer ones 5½ inches. The middle section is provided with a series of buckets inclined and opening towards the higher-water-level. The lateral sections are similarly divided, but the buckets are inclined in the reverse direction, and do not reach to the same height as in the central compartment, the space thus left being occupied by small directing plates, three to each bucket. The water is let into the fish-way through a sluice in the dam, 2 feet wide and 6 inches deep, and the interior cellular floor of the way is bevelled off level with the bottom of the sluice. The water passing through the sluice tends continually to sink to the middle line of buckets and to emerge at the sides at a lower level; the difference of head and the directing plates (which slant the same way as the buckets in the middle section) cause it to bank up on the sides and feed back to the middle of the way. The sinking in the middle is thus compensated, and a constant depth and constant velocity is maintained from the top to the bottom. In this manner, although the water appears to be running down a straight course of an inclination as great as 1 in 3, the velocity is readily preserved as low as 3 (or even 2) miles an hour.

F. G. D.

Cofferdams in Flooded Rivers. By M. Lanteirès.

(Annales des Travaux Publics, 1880, p. 4.)

The Author describes the erection of masonry piers or cofferdams for two bridges over the Garonne at Muret and at Cazères, during the time of the high floods of that river in 1875, when three out of four cofferdams were carried away. The bed of the Garonne, throughout the greater part of its length, consists of a tufa, or clayey sandstone, composed of schistose sand agglomerated by an argilo-calcareous gangue. These cofferdams were built in the ordinary way with wood piles 10 inches in diameter, driven for 19 to 31 inches into the tufa. In driving the piles the tufa was splintered and broken up, so that the hold of the piles was very insufficient, and the buoyancy of the woodwork made it easy for the flood-stream to carry it away. In rebuilding the cofferdams, wood piles were used only at the meeting of the ends of the longitudinal timbers or binders, the intervening panels of sheet-piling being supported by bar-iron piles 2·38 inches diameter clamped between the binders. The wood piles were 12 inches in diameter, provided with shoes with lancelike terminals 20 inches in length, driven into the tufa at the bottom of holes bored about

3 feet deep, with a 10-inch spiral auger. At about this depth boring was generally stopped by meeting a hard substratum, into which the pointed shoe only was driven. The bar-iron piles were driven about 6·5 feet into the tufa without materially breaking it. The piles were from 5·24 to 6·3 feet apart, and were 27 feet in length. The sheet-piling was 4 inches thick, two rows only of horizontal binders about 7·5 inches square being used. The double rows of piling of these dimensions were 5·24 feet apart, the interspace being filled in with tempered clay let down in blocks and well rammed. The dams so made, though light, were successfully used in completing the work. A statement of the cost of the dams in detail is given.

W. W. B.

New Wet Dock at Bordeaux.

(Annales Industrielles, Jan. 4th, 11th, 18th, 1880; cols. 11, 44, 86.)

The new dock at Bordeaux, on the Garonne, designed by, and constructed under the direction of, M. Joly de Boissel, was commenced in May 1869, and was opened in October 1879. The area occupied by the dock works amounts to 128¾ acres. The area of the water surface of the dock is about 25 acres; the length of the dock is 1,954 feet; and the width of the waist is 396 feet. At the upper end, the dock is formed with a transverse head, 1,072 feet in length. At the lower end, next to the entrance, the dock is enlarged to a width of 528 feet, to facilitate the movements of large ships. It is from 30 feet to 33 feet deep below the top of the walls; and at high-water spring tides it holds 23½ feet in depth of water. The dock is capable of holding seventy-six ships, and it presents a quayage nearly 6,000 feet in length.

There are two locks, side by side, from the river. One of them, intended principally for paddle steamers, is 72½ feet wide, and 501 feet in clear length; the other is only 46 feet wide by 449 feet long; and it is provided, nearly at mid-length, with an additional pair of gates, to economise water in the passage of the smaller vessels. The floors of the locks are inverted arches, except under the gates.

The average thickness of the dock walls is equal to $\frac{4}{11}$ of the height. The profile is parabolic, and counterforts are built at distances of 165 feet between centres, in order to subdivide the thrust from behind. The quayway is about 60 feet wide.

A reservoir, 40 acres in superficial extent, has been constructed beyond the dock, from which the level of the water in the dock may be maintained when an auxiliary supply of water is required.

D. K. C.

Marseilles Docks. By M. Duteil.

(Resumé de la Société des Ingénieurs civils, 1879, p. 273.)

M. Duteil reports on the present state of the docks, warehouses, and new port of Marseilles, constructed in 1856–62. They occupy the two basins of the Lazaret and Areno, offering an area of about 17,800 square yards, thus occupied:—

	Square Yards.
Quays	1,408
Carriageways	1,803
Warehouses	12,260
Offices and sample rooms	2,329
	17,800

In addition to these, there are the quays of the outer breakwater, the north quay of the Joliette basin, and the south quay of the basin of the marine station. The company, besides, hold the concession of the graving docks. There are 27,600 square yards of shed on the quays, for the examination of merchandise, with lines of rail and wagons. The total length of quayage available amounts to upwards of 10,000 feet.

Thirty-eight hydraulic cranes, of which twenty-two are capable of lifting 1 ton and sixteen can lift 3 tons, are employed for unloading and loading ships. There are 12½ miles of railway, with one hundred and seventy turntables; of these, several were to be fitted with hydraulic machines. The water-pressure is supplied by two engines, with accumulators, giving a pressure equivalent to a column of water 1,650 feet high, about 720 lbs. pressure per square inch. The water-mains, laid deep enough to be beyond the reach of frost, are cast on end in 9-feet lengths of iron twice melted, and proved to a pressure of 85 atmospheres. The pipes are 5 inches in diameter, and 1⅜ inch thick. The efficiency of the hydraulic machinery is only 30 per cent., but it is nevertheless of advantage to supply it, as the quays are kept clear of bulky steam-cranes. The hydraulic cranes are placed in groups of three at intervals of 72 feet. The groups are arranged at intervals of 360 feet. The lifting apparatus of the cranes consists of a cast-iron cylinder, 10 inches in diameter, 7 feet 10 inches long, having a cast-iron plunger 6¼ inches in diameter, with a stroke of 7 feet, with two blocks of three pulleys each for multiplying the power.

M. Barret, in 1868, ascertained that, with a vacuum of 14 inches of mercury, corn could be drawn up to an elevation of 5½ feet; and he constructed an apparatus for the discharge of grain, based on the vacuum principle. It consisted of two vertical cylinders, terminated by two conical appendages, worked alternately, each of them having a sliding door at the lower end to discharge the grain. A vertical telescopic tube is plunged into the hold of the

vessel, and acts as inspirator. The upper end is branched to each cylinder. The apparatus is suspended from the jib of a crane, by means of which it is placed over the hold. By this apparatus 35 cubic feet of grain can be raised 30 feet high in two minutes.[1]

The repairing establishment consists of a receiving dock or basin, a basin for reparation on pontoons, and four dry docks. The principal dry dock can receive a vessel 430 feet in length. Four steam-engines are employed to work centrifugal pumps, by which 10,000 cubic mètres of water are raised per hour. Centrifugal pumps are preferred to other pumps for this service, as they are simpler and require less maintenance. The floating dock is of wood. An engine of 15 HP. is sufficient to lift this dock in three and a half hours. It cost, in 1846, £14,000. It is 211 feet long, 56 feet wide, 23 feet deep; its draught of water is 2¾ feet, and its displacement is 965 tons. It is in contemplation to erect a hydraulic-lift graving dock on the system of Mr. Edwin Clark.

D. K. C.

The New Harbour at Trieste. By F. Bömches.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereins, 1879, p. 99.)

A general description, by the same Author, of the plan and construction of this important undertaking has been already abstracted.[2] The works are now nearly completed, and as great part have stood for four years and have suffered no injury, even from the exceptional storms of the winter of 1878–79, their success may be considered to be established. The main difficulty in construction arose from the fact that the foundations consisted everywhere of a mixture of soft earth and clay, of unknown depth; borings to 60 feet below the surface having failed to pass through it. In such circumstances the sinking of piers by the pneumatic process was considered too expensive, and piling too uncertain a method to be adopted; it was therefore resolved to improve the bottom by throwing in a mass of solid materials, and to build the quay walls, &c., upon these. This system, with the important modifications found necessary in the course of the works,[3] have proved thoroughly successful. The effect of the pressure of the rubble foundations of the quay walls on the stratum of clay (which had a seaward slope of 1 in 25) was very remarkable. The bottom outside began to rise for a distance of 180 yards out from the foundations, and to a maximum height of 33 feet. The dredging of this elevated soil to the required depth produced fresh movements in the rubble

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. liv., p. 348.
[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xlvi., p. 288.
[3] *Ibid.*, p. 289.

foundations. These were therefore supported by driving a row of piles along the whole line of the wall.

Similarly the weight of the breakwater, which is built in 54 feet of water, produced a sinking of the natural bottom along its axis to an extent of 26 feet; and a corresponding rising, outside the toe of each slope, to an extent of 11½ feet on the outer, and of 15 feet on the inner side of the breakwater. There has been a slow settlement of the breakwater ever since its completion, amounting, on the whole, to 2 feet; but the rate decreases year by year, and has not been accompanied by any cracking or disturbance of the masonry.

The first basin has now been open since July 1875, and has accommodated a large amount of trade. The second basin was opened in November 1877, but the side next the town still remains unfinished. The third basin was ordered, in 1877, to be abandoned. Settlements similar, but inferior to those of the breakwater, have occurred in the walls of these basins, also without any injury to the masonry. The petroleum basin is now in progress.

W. R. B.

The French Railway System in 1877–78.

(Revue générale des Chemins de fer, vol. i., p. 440.)

The total length of railways in France, constructed or sanctioned, at the 31st of December, 1878, amounted to 21,955 miles; of which 15,177 miles were in work, 2,664 miles were in course of construction, and 4,114 miles were sanctioned, but were not yet commenced at that date. The 15,177 miles open were composed as follow:—

	Miles.		Per Cent.
1. The railways of the six principal companies .	12,137	or	80·0
2. The circular railways (de ceinture) . . .	17	„	0·1
3. Lines worked by various companies . . .	621	„	4·1
4. State railways	984	„	6·5
5. Industrial and other lines	145	„	0·9
6. Secondary railways (d'intérêt local) . . .	1,273	„	8·4
Total length	15,177		100·0

The constituent mileages of the six principal railways, making up 12,137 miles, open, were as follow:—

	Double Line.	Single Line.	Total.
	Miles.	Miles.	Miles.
Northern railway	849	343	1,192
Eastern „	1,051	514	1,565
West „	779	988	1,767
Orleans „	775	1,911	2,686
Lyons and Mediterranean railway	1,537½	2,021½	3,559
Southern railway	427	941	1,368
	5,418½	6,718½	12,137

The proportions of double-way, in the lengths of line open, are as follow :—

	Double-way. Per Cent.
On the total length of line open (15,177 miles)	35·9
On the 12,137 miles worked by the six companies . . .	44·6
On the 621 miles worked by various companies	1·6
On the 984 miles of state railways	0·63

At December 31, 1877, the total length of open line of the six great companies, amounted to 11,225 miles; and the capital cost amounted to £295,660,341, being at the rate of £25,780 per mile. The gross receipts during 1877 amounted to £32,404,799; and the expenses to £16,299,922; leaving a balance, net receipts, £16,104,877; and showing that the expenses amounted to 50¼ per cent. of the receipts.

D. K. C.

Note on the Present System of Permanent Way on the Six Chief Railways of France. By E. Lecocq.

(Revue générale des Chemins de fer, vol. i., p. 37.)]

Steel rails are now almost exclusively used, but the section and weight of rail differ widely. The Eastern, the Northern, and the Paris, Lyons, and Mediterranean companies use only the flange rail; but the Orleans, the Midland and Western use also the old double-headed rail. The flange rail used on the Northern, and on recent extensions of the Western lines, weighs 60½ lbs. per yard, and is noticeable chiefly for the small width of the base (3$\frac{13}{16}$ inches), as compared with the height (5 inches bare). This type of rail was introduced on the Northern some six years ago, so presumably it has proved satisfactory.

The Eastern company uses also a 60½ lbs. rail, but the height is reduced to 4¾ inches, and the base increased to nearly 4 inches.

The Lyons company employs two sections, the heavier one weighing 77½ lbs. per yard, and measuring 5⅛ inches high by 5⅛ inches wide, and the lighter one weighing 66½ lbs. per yard, and measuring 5 inches by 4 inches base.

The width of head as a rule is 2¼ inches, and the length of rail about 26 feet. With the exception of some practically obsolete types of "pear-headed" rail, the angle for fishing is ½ to 1, and the thickness of web in most instances is rather less than ½ inch.

A diagram and table, illustrating the arrangement of the sleepers and joints, lead to the following conclusions:—

1. Suspended joints are adopted by five out of the six companies, the Northern alone putting a sleeper under the joint.

2. The spacing of the sleepers next the joint is always about 2 feet from centre to centre.

3. On the Lyons and on the Western railways, the sleepers next to those at the joint are spaced a less distance apart than the remainder. This also is necessarily the case on the Eastern and Northern lines, because the fish-joints are not opposite each other, but lap about 2 feet.

4. Expedients to prevent the longitudinal movement of the rails are adopted by five out of the six companies.

5. Finally, it appears that, with the exception of the Lyons company, the weight of the flange rail track is about 323 lbs. per yard, while the double-headed way attains a mean weight of 403 lbs. per yard. This excess of 80 lbs. per yard is considered by the Author to be eminently favourable to stability, especially with the heavy loading and great speed of modern trains.

The following are matters of details not shown in the table, but considered worthy of notice:—

1. Four bolts are now invariably used for fishing, instead of three, as was commonly the case some time ago.

2. Grooved fishes are used by three of the companies; the others use shoulder bolts.

3. Wood screws are exclusively used for fastening the rails and chairs by the Eastern, Northern, and Western companies, and by the Lyons company for their lighter rail. Trenails are still used for fastening the chairs by the Southern and Orleans companies. The Lyons company fasten their heavy rail with a fang bolt on the outside, and a trenail on the inside of the $5\frac{1}{8}$ inches flange.

B. B.

On Iron Cross Sleepers, and the mode of securing the Rails to them. By A. Müller.

(Organ für die Fortschritte des Eisenbahnwesens, 1879, p. 175.)

The introduction of longitudinal iron sleepers on existing roads presents the great difficulty that, owing to the length of time required for re-laying, the part of the track so occupied must be withdrawn from traffic. This occasions great inconveniences on double lines, and on single lines makes the operation impossible. The great care needed in preparing and drilling the sleepers, especially for curves, and the difficulties of handling arising from their weight, are further objections. None of these apply to the cross-sleeper system, in which the wooden sleepers can be replaced one by one, just as they become unfit for traffic. On the other hand, iron cross sleepers are said to oppose too little resistance to sideways shifting on curves. This has been obviated by riveting on angle or T-irons underneath. A simpler plan is to bend over the end of the sleeper at right angles, having first cut a triangular notch in each of the sloping sides to facilitate the bending. A more

serious objection is the many kinds of fastenings that are required, to suit curves of different radius and different spread of gauge. The number, however, can be very greatly diminished. If the fastening is by hook-bolts and clips, the variation can be made by giving a greater or less thickness to the vertical part of the clip, the holes being in all cases the same. A Table shows that any spread of gauge, up to ¾ inch, can be given with only three patterns of clip. The hook-bolts are best locked by means of spring washers under the nut. Similarly, if the fastening is by gib and cotter, the cotter and the holes may be made the same throughout, the breadth of the two gibs being varied. Four patterns of each of these are shown to be sufficient; they should be distinguished from each other by grooves or other marks, given in rolling.

W. R. B.

Longitudinal v. *Cross Sleepers for Iron Permanent Way.*

By H. Claus.

(Organ für die Fortschritte des Eisenbahnwesens, 1879, p. 272.)

In discussing the introduction of iron sleepers, it has often been remarked[1] that cross sleepers are to be preferred to longitudinal, because existing roads with wooden cross sleepers are easily converted in the one case, whereas it is impossible to do so in the other without much expense and hindrance to traffic. The Author says that this is not the case, and that the latter change has been carried out with success in many instances, notably on the Eastern Railway of Prussia. He has himself been in charge of the re-laying of 6 miles of line with iron longitudinals, which has been effected without any interruption to traffic. Here the rails and sleepers, supplied from the works ready punched, were put together on the ground, close to where they were to be laid. This process gave occupation to the workmen at such times as the traffic did not permit them to work at re-laying, and also rendered the transport easier. The routine of re-laying was as follows. Before the arrival of the last train, some of the fish-bolts and spikes on the length to be re-laid were loosened; and as soon as the train had passed, the whole length was broken up and lifted to one side. The bed for the longitudinals, and for the cross sleepers at the joints, was then prepared, the longitudinals with the rails upon them were put in place, and the cross sleepers, tie-rods, and fish-plates were then connected to them. The cross sleepers at the joints were made of timber, for quickness of handling. The junction of the old road to the new was then made by means of

[1] *Vide* preceding abstract of paper by A. Müller.

special joint pieces and fish-plates, fitted to the old section at one end, and to the new at the other; the new track was levelled, straightened, and packed, and it was then ready for another train. In an interval of four hours, about twelve rail lengths (about 120 lineal yards) could thus be laid with a force of twenty-five ordinary plate-layers, who were found to fall into the work very rapidly.

The Author holds it to be proved that the continuous bearing of a longitudinal sleeper gives the greatest firmness and stability to a railway. The cross-sleeper system only came in because wooden longitudinals were costly, and liable to decay; but with iron this objection does not exist. The drainage is quite as easy with longitudinals, if the ballast be good. The load is better distributed, and the motion more even. In most cases the cost is also found to be less.

W. R. B.

Metallic Permanent Way, Serres and Battig's System.

By J. L. Mercadier.

(Revue générale des Chemins de fer, vol. i., p. 322.)

The Author recognises that the various systems of metallic ways of railways are reducible to three types:—the simple rail, represented by the Barlow rail, and the Hartwich rail; the way in two parts, of which Hilf's[1] and Vautherin's[1] are instances; the way in three parts, represented by the metallic way of Serres and Battig. In this system, the rail, which consists of a head and a vertical web, is sustained upon and between two longitudinal sleepers, which are rolled with a splay, so that, when they are fixed together to the web of the rail, they form an opening like an inverted V resting on the ballast. They are rolled with flanges at the base, which rest horizontally on the ballast, and augment the width of the bearing surface, making a total width of 12 inches. The attachment of the sleeper to the rail is made by means of a cotter; but the real duty of binding them is discharged by the transverse ties, which are 4 inches deep, are passed through openings formed in the web portions of the sleepers, and rest on the base-flanges, which are notched at the upper edge, to receive and firmly to embrace the web of the rail and the upper junction-flanges of the sleepers. Intermediate short pieces, or tenons, of the same section as the iron ties, are applied for fixing the rails. By such combination, it follows that the load on the rail has the effect of tightening up every connection and increasing the firmness

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlix., p. 252; vol. xlvii., p. 322.

of the bond. The quantities for 1 mile of way of the ordinary gauge are as follow :—

Piece.	Number of Pieces per Mile.	Length. (about)	Weight per Yard.	Weight.	
				Per Piece.	Per Mile.
		Feet.	lbs.	lbs.	Tons.
Rails	380	27·5	37	341	58·5
Longitudinals	760	27·5	32⅝	299	102·3
Cross-ties	380	5·7	26	49·5	8·5
Tenons	3,814	..	26	5·94	10·2
Split-cotters	3,814	..	0·26	0·26	0·5
Total	..	..	..	..	180·0

The total weight is at the rate of 228 lbs. per lineal yard of way.

From comparative Tables, it appears that the costs per lineal yard range as follow :—

System.		First Cost.		Maintenance per Year.	Renewal.
		s.	*d.*	*d.*	*d.*
Way on cross-sleepers of timber . .	per yard	20	7	2	11·9
Hilf's way	”	23	3	..	..
Hilf's way, modified	”	25	7	1·83	6·26
Serres and Battig's system. . . .	”	22	6	1·83	4·18

The last column is calculated on the basis of a life of twenty-five years for the rail, sixty years for the longitudinals and ties, and twelve years for the wood sleepers.

D. K. C.

Railway on Mount Vesuvius.

(Annales Industrielles, 1879, col. 520.)

The works of the Vesuvian railway are now in course of construction. A substantial carriage road has been formed, from the observatory to the foot of the great cone. The ascent of the cone is to be made by means of a double-rope railway, worked by a stationary engine at the foot. The site that has been selected for the railway on the west side, is, it is considered, free from invasion by lava. The height of the incline is 1,410 feet above the station, which itself is 2,624 feet above the sea-level. The average gradient is 56 per cent., or about 1 in 1¾; the maximum gradient is

63 per cent., or about 1 in 1⅗. As the surface of the cone is loose and cindery, a solid foundation of continuous planking, to carry the rails, has been laid by Sr. Olivieri, the engineer in charge.

The carriages are so constructed that they cannot leave the rails. The ropes, of steel wire, have been tested to a proof stress ten times the working stress; but each carriage is fitted with a powerful self-acting brake, which will come into instant action in the event of a breakage of the ropes. Two large reservoirs have been constructed for the supply of water for the engines.

D. K. C.

On the Kriegsdorf and Römerstadt Light Railway.

By L. Huss.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereins, 1879, p. 106.)

This railway is 8½ miles in length, and is a branch of the main line from Olmütz to Jägerndorf, forming part of the Central Silesian railway. It was begun in 1876, as a light railway of standard gauge, to be built with every possible attention to economy, and to be limited as to speed to 9 miles per hour. It winds by easy gradients up a valley, between hills yielding excellent building stone. The curves are numerous; three of them having the minimum radius of 490 feet. The maximum gradient required is about 1 in 80; but this is made up by using a gradient somewhat steeper on the straight road (1 in 72), and somewhat less steep on curves (1 in 102 on the sharpest), with the view of equalising the tractive resistance throughout. The rule used was to diminish the gradient by $\frac{1}{1 \cdot 5 \times (\text{radius of curve})}$; and experience on this line shows it to be pretty correct. The formation width was 13 feet at bottom and 10 feet at top, the depth of the ballast being about 1 foot. Drawings and particulars of the standard walls, abutments, &c., are given. For much of the distance the line runs close by the side of the river Mohra. Wherever a strip of land intervened between the two it was protected by wattling and by the planting of willows. Where the two were contiguous, the outer side of the railway bank was made of a mass of dry rubble, bedded horizontally, not vertically, so that the stones might be less liable to slip down in case of a slight breach being made. Details are also given of the arches, which were laid in rubble masonry; this construction being allowed by the State Railway Department for spans not exceeding 19 feet 6 inches. They were covered over with a layer of concrete 4 inches thick, and then with at least 2 feet 4 inches of sand, earth, or gravel.

Full particulars as to cost of material and labour are given, which are summed up as follow:—

——	Florins per Kilomètre.	£ per Mile.
Excavation, earth and rock	3,110	520
Road-making at stations, &c.	250	41
Special works for protection against river	360	60
Bridges and culverts, including girders and flooring	3,390	565
Total up to formation level	7,110	1,186

For the bridges the conditions laid down were, that all over 6 feet 7 inches span were to be of iron, and that the working load was not to exceed for rivets 700 kilogrammes per centimètre (9,960 lbs. per square inch), and for other pieces 900 kilogrammes per centimètre (12,800 lbs. per square inch). Under these conditions the small road bridges, 7 feet between bearings, were made at a total weight of 9½ cwt. There were two girder bridges, one with the roadway at the bottom of the main girders, the other at the top. In the latter case, owing to deficiency of headway, the depth was taken only $\frac{1}{16}$ the span, and the sleepers were longitudinal, laid, as in small bridges, directly upon the top of the main girders, without any cross girders intervening. This has the advantage that the sleepers (being of iron) can be treated as part of the girder, and allowed to take their share of the load. These bridges were contracted for at the price of about £22 per ton, including staging for erection and painting. In order to test whether, at any subsequent time, any set of the girders in these bridges had taken place, they were marked, some weeks after the opening of the line, by a series of centre pops along a horizontal straight line upon each girder, visible throughout its length from a point on the adjacent bank. By levelling from this point along these pops (which were distinguished by a streak of red paint) the deflection of this original horizontal line can at any time be observed.

The rails used were of steel, weighing 47½ lbs. per yard; the section being such as to give a maximum load of 14,200 lbs. per square inch. The length of rails in the straight road was 23 feet, with suspended joints. The sleepers were of fir, not creosoted, and for the most part only 5⅞ inches broad. On account of their narrowness nine were allowed for each rail length of 23 feet, instead of eight, as usual. The ballast, including laying, cost 0·96 florin per cubic mètre (1*s*. 5*d*. per cubic yard); and the total cost of the ballast and permanent way (including stock of materials and maintenance for four months) was 8,880 florins per kilomètre (£1,460 per mile). It should be noted that the price of the steel rails was very high (over £12 per ton); but, on the other hand, the sleepers were supplied by parties interested in the line, at about ⅓ their market value.

The railway was unfenced, except at certain parts in the neighbourhood of roads, and where shedding was required as a protection against snow. Level crossings were adopted throughout. The rolling stock consisted of two six-wheel tender locomotives, weighing about 26 tons each, two vans, and four carriages; the total cost being 4,680 florins per kilomètre of road (£780 per mile). The line was opened for traffic in October 1878. Three trains have been run daily each way, carrying about 900 passengers and 1,800 tons of goods per month; and the total receipts have been at the rate of about £10,000 per annum.

It is to be observed that, as regards the character and solidity of the works, the line is not inferior to main lines, from which it is distinguished mainly by the lower speed and lighter rolling stock. The total cost of the line, including everything, has been about £49,000, or £5,800 per mile. This is less than that of any of the second-class railways in Hungary, except two, which have unusually favourable conditions; and far less than of any of the second-class railways in Austria. The Author considers that it might well have been reduced by diminishing the formation width by about 1¼ foot, giving steeper slopes to cuttings and embankments, using timber for the bridges, lighter locomotives, and steel rails of only 20 kilogrammes per mètre (40 lbs. per yard). The fact, however, that, despite its small traffic, this line can be worked at a profit, shows the great economy that may be effected by a reduction in speed, and a consequent suppression of all the sources of expense which high speed necessitates.

W. R. B.

On an Inclined Railway at the Giessbach, Switzerland.

By R. Abt.

(Die Eisenbahn, vol. xi., p. 97 *et seq.*)

The cascade of the Giessbach, on the lake of Brienz, has of late years become a favourite resort of Swiss tourists, and to meet the demand for accommodation a large hotel has been built. This is placed on a cliff, about 303 feet above, and 1100 feet back from the lake, from which it is separated by the channel of the Giessbach, the approach being by a circuitous foot-path on the right bank of the stream. In order to render the place more accessible, a concession was granted by the Swiss Government, in December 1878, for the inclined railway described by the Author.

This is a single line, with a middle crossing place, on the mètre gauge, with a central rack rail. The average gradient is 28 in 100, rather more than half the total length (187 mètres out of 346 mètres) being carried upon a wrought-iron bridge of five spans of 38 mètres each. These are arched trusses; the roadway is carried by a straight [iron beam, weighing 28·23 kilogrammes

per mètre, above a segmental arch of ⊥ section of 27·25 kilogrammes per mètre; the two members, which are 6·20 mètres vertically apart at the springing, and 1·07 mètre at the crown of the arch, being united by struts and diagonal ties of L iron, from 13 to 9 kilogrammes per mètre. The roadway is formed of ⌒ iron (*zores*) cross beams, 15·5 kilogrammes per mètre, placed at intervals of 1 mètre, which carry the plank footway, 60 centimètres wide, besides doing duty as sleepers for the rails. The crossing place for the carriages is on the bottom span, which is therefore wider and heavier than the others, its total weight being 18 tons, or 0·497 tons per lineal mètre; the other four spans weigh respectively 15·6, 11·8, 11·8, and 10·6 tons, making a total of 68 tons for the whole bridge. The piers and abutments are in dressed masonry. The rails are of wrought iron, flat-bottomed, and weighing 16·75 kilogrammes per mètre. On the bridge they are attached by cast-steel shoes clipping the flanges to the iron cross sleepers. When the line is in earthwork, oak sleepers, and iron spikes of the ordinary pattern, are used. The rack rail is made with] iron sides, and teeth of trapeziform section, having a pitch of 101 millimètres riveted through them. It is put together in segments of 3 mètres long, weighing 96 kilogrammes, or 32 kilogrammes per mètre, and is carried by continuous longitudinal beams of ⊔ iron over the wooden sleepers.

The traction is on the water-balance system, the descending carriage drawing up a second loaded one by means of an excess weight of water carried in a tank in the under frame, the two being united by a steel wire rope passing over a reversing pulley at the upper end of the line. The rope weighs 700 kilogrammes; it is made of the best English cast steel, of a total section of 2,198 square millimètres in seventy wires, of 2 millimètres diameter; has a breaking strain of 30 tons, or about 150 kilogrammes per square millimètre. The carriage is about 11 mètres long, divided into six compartments, one for luggage, and the other five with seats for forty passengers: it is carried on six wheels, of which the two uppermost are a transverse axle carrying the toothed wheel and the brake drum; while the other four are attached to a bogie frame of 2·2 mètres base below. The distance from the centre of the bogie to the upper axle is 4·5 mètres, giving a total wheel-base of 5·6 mètres. All the wheels have bronze bearings and run loose on their centres. The brake drums are of cast steel, 52 centimètres diameter, and the brake blocks of bronze. A safety catch, formed by a toothed rod, is attached to the coupling hook, which, in the event of the rope breaking, falls into the hollow of the rack-rail and stops the carriage. The wheels of one carriage are flanged on the inside, those of the other on the outside, of the rail; so that, on arriving at the crossing point, one invariably goes to the right and the other to the left. The total weight of the carriage empty is 5·3 tons; the capacity of the water cistern is about 5½ tons.

The load to be lifted varies from 6 to 9½ tons, which corresponds

to a descending counterpoise of between 7·3 and 10·8 tons, or the amount of water expended at each trip may vary between 1·6 ton and 5·8 tons. The latter quantity can be filled and discharged in about a minute.

The maximum speed allowed by the concession is 1 mètre per second, making 346 seconds, or about 6 minutes for the trip; a speed which, the Author remarks, may be considered as somewhat snail-like, but nevertheless, when compared with that of the Swiss lines, with the ordinary valley gradients of about 6 in 1000, represents a high comparative duty; the 93 mètres of vertical height corresponding to a length on the lower gradient of 15·6 kilomètres, and to traverse this in 6 minutes a speed of 156 kilomètres per hour, or double that of the fastest express train in England, would be required. About 4 minutes are required for the necessary operations of loading and unloading the carriage at either end; so that the trains succeed each other at intervals of 10 minutes during the working season, which lasts from 15th June to 15th September usually.

The works of the line were commenced at the end of October, 1878, and the line was opened for use on the 20th of July following. The cost is stated at 146,880 francs, and the annual working expenditure at 3,640 francs. At the close of the first working season on the 30th September, 1879, one thousand eight hundred trains had been run, carrying twenty-eight thousand persons, without the slightest accident. The total receipts were 18,300 francs, equal to a gross return of 9·97 per cent. on the capital, or allowing 5 per cent. as interest, and 4 per cent. as a reserve fund for renewals, there was nearly 1 per cent. surplus, apart from the amount saved in transporting provision, stores, coal, and other heavy articles to the hotel.

H. B.

Avalanches on the Salzkammergut Railway. By M. Morawitz.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereins, vol. xxxi., p. 54.)

The Salzkammergut railway was opened for traffic in October 1877, and it is noted that the avalanches occurring in the following winter were of a magnitude unequalled for sixty or seventy years back.

To the left of one part of the line there is a glade on the wooded slope of a hill which is surmounted by a plateau. This glade forms the passage for the descent of an avalanche, which, making its appearance in February 1876, lay 2·6 feet deep over the railway. For the future protection of the line it was thought sufficient to raise a wooden fence on the slope of the hill; but the snow in the winter of 1877–8 destroyed

the fence. A snow hurdle was then erected, no longer on the slope, but on the plateau itself, at a proper distance from its edge, so that the formation of a snow shield, and the consequent precipitation of snow, was thereby obviated.

At another part of the line, where it runs in a cutting at the foot of a mountain, earthen tracks, formed with a slope of 1 to 1½, for the transport of wood, provided passages for the descent of avalanches. At various points near the foot of these tracks piles of firewood had been left, and the snow of January 1878 overturned these piles, and, carrying them along, caused deep cuts in the railway embankment. To prevent a recurrence of this, traverses were placed in the tracks, in such a way that the cross rails between the traverses, which are sunk into the ground, can be raised at pleasure for the passage of wood, and again closed.

The part most exposed to avalanches is the Koppenthal. Here the snow comes down a channel lying between the slopes of two ridges of the Saarstein, up to the highest peak of which the channel leads; and the main avalanche is supplemented by numerous side branches. Opposite the lower end of the channel, which lies on the right side of the Traun, there is, stretching to the left of the river, an old bed; the railway cuts off a part of this old bed from the present one, and between the line and the river an earthen embankment, with a stone facing on the river side, was raised for protection from avalanches. This embankment proved sufficient in the winter of 1876–7, but not so in the one following. Firstly, in January 1878 an avalanche came down, filled up the bed of the Traun, and shot over the embankment to the right side of the railway. The dammed-up water of the river then gradually rose, and at last broke over the embankment, making a breach 12 yards wide in it, and passing the railway to the old Traun bed. Again, in March of the same year, several avalanches, succeeding one another by the same channel, overshot river, embankment, and railway, attaining a maximum breadth of 656 feet along the river, of 590 feet along the line, with maximum depths of 98 feet and 36 feet over river and line respectively, while the snow was pushed up the opposite slope to a distance of about 656 feet beyond the railway. These avalanches in part directly, and in part by the great pressure of air preceding them, broke down trees of sixty years' growth over an area of 5 to 7½ acres. The breach made in the embankment by the earlier avalanche of the same year, and which had been repaired by this time, was again opened, and the Traun once more flowed over its old bed; but thirty hours after the fall of the last avalanche the Traun had made its way into its regular channel through a snow tunnel. The earth embankment was therefore replaced by one formed entirely of large blocks of stone; the old river bed was filled up; whilst, in its stead, and for the purpose of carrying away the water of the Traun after it has overflowed the embankment, a channel of sufficient size was formed between the latter and the railway. The bottom of the

channel, at the place where it has to receive the dammed-up water, is 16½ feet broad, and is formed of paving 12 inches deep, protected against underwashing by wooden beams placed along and across it, whilst its sloping sides are plastered. A trench has been made on the embankment to conduct the water into the prepared channel, which is, below this point, further strengthened by a course of 2-inch planking.

The last stretch of the Salzkammergut railway, which is exposed to avalanches, lies along the western shore of the Traun lake. Here for some distance the line forms a cutting on the slope of a mountain-chain, which rises at one place to a peak called the Sonnstein. Beneath this peak the railway lies on a steep, rocky slope previous to its entrance into the Sonnstein tunnel. Immediately before the tunnel lies the termination of an avalanche channel, across which the line is carried on an iron bridge. In the winter of 1877–8 several avalanches succeeded one another at this place, leaving the snow lying from 10 to 13 feet deep over the bridge and the rest of the line up to the mouth of the tunnel. Inspection of the ground showed that the most dangerous locality for the precipitation of avalanches in this neighbourhood was at a height of 1,150 feet above the railway; for at this level there occur perpendicular walls of rock 16 to 50 feet in height, whilst upwards from these run steep and bare clefts in which heaps of snow accumulate, till by their own weight or by sudden change of temperature they slide down and tumble over the perpendicular walls. By this means snow masses lying in secondary or main channels are drawn into motion, this again leading to a partial movement of the snow lying on wooded lands bordering on the channels. Here the method that seemed most likely to be successful in affording protection to the railway was the construction, in the clefts above mentioned, and at the foot of the low rock walls, of small traverse works, such as those which have proved most successful in Switzerland. These traverses give sufficient protection from avalanches to allow of the planting of trees on the slopes of the various channels, and when the trees are half grown they prevent the fall of avalanches, rendering the further maintenance of structures for this purpose unnecessary. The traverses or barricades placed in the clefts reached a height of about 15 feet, the others ranged in height between 5 and 6½ feet, and in length between 6½ and 26 feet.

A. Br.

The Slipping of Locomotive Driving Wheels.

By J. de Laboriette.

(Revue générale des Chemins de fer, Jan. 1880, pp. 21–31.)

The slipping of locomotive driving wheels in regular working, particularly at high speeds and down hill, was brought into pro-

minence by M. Rabeuf's experiments[1] on the Northern Railway of France, which showed as much as from 13 to 25 per cent. of slipping; and this result afterwards formed the subject of a confirmatory theoretical investigation by Signor Oppizzi.[2] With a view to clearing up a matter of so much interest and importance in the working of locomotives, further careful experiments were made by the Author last summer on the same railway. The trials were conducted on five express engines, one engine uncoupled and four engines having four wheels coupled, and on one four-coupled engine with smaller wheels; and were made with six of the regular trains, some heavy and some light, running between Paris, Creil, and Amiens, the maximum gradient being 1 in 200; the speed averaged 43½ miles per hour, and rose sometimes to 57 miles. The exact circumference of the driving wheels was accurately determined by direct measurement of the distance traversed per revolution in rolling them slowly along the rails, instead of by measuring their diameter. Each individual revolution was automatically recorded by a Morse instrument[3] upon a continuous paper ribbon, across which a transverse mark was made by the observer on passing every mile-post.

The discrepancies between the recorded revolutions and the theoretical number corresponding with the distance run were found to be so minute that they did not exceed a maximum of 0·154 per cent., or 2·84 revolutions in a distance of 7½ miles; the minimum was 0·004 per cent., or 0·2 revolution in 20 miles. In several instances the discrepancy was on the wrong side, the recorded revolutions being even fewer than the number theoretically proper; and the falling gradients showed no contrast with the rising. The results are tabulated in detail; and from their examination the Author concludes that the observed discrepancies are no greater than what may be due to possible errors of observation, and are altogether too insignificant to be attributable to any such slipping as that previously alleged. He considers, therefore, there is no ground whatever for fearing lest either waste of engine power or wear of tires may arise from such a cause.[4]

A. B.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. liii., p. 346.
[2] *Ibid.*, vol. lvi., p. 317.
[3] See also "Engineering," 9 April, 1880, p. 287.
[4] It will be noticed that in these experiments, unfortunately, no higher speed than 57 miles per hour was attained; whereas in the former trials by M. Rabeuf the speed reached 74½ miles down the gradient of 1 in 200. These later trials, therefore, can hardly be regarded as a complete refutation of the results obtained from the former, or of Signor Oppizzi's investigation.—A.B.

On the Evaporative Power of Locomotive Boilers.

By O. Busse.

(Organ für die Fortschritte des Eisenbahnwesens, 1880, p. 16.)

The evaporative power of locomotives has usually been determined in practice by the simple rule that it is at the rate of 40 litres per hour per square mètre (0·13 cubic foot per square foot per hour) of total heating surface. This answers fairly for ordinary engines, but is inapplicable to abnormal types, or to engines with short tubes, &c. It is most desirable to know the relative effect of the fire-box and tubes, and that of long as compared with short tubes. For this purpose the Author has analysed the experiments made on the Northern Railway of France, and given in Couche, "Voie et Materiel roulant des Chemins de fer," vol. iii. Here the barrel of an old locomotive boiler was divided into four equal compartments by iron bulkheads, and was then fired up with the aid of a blast obtained from another boiler. It had one hundred and twenty-five tubes of 46 millimètres (1·8 inch), internal diameter, and 3·68 mètres (12 feet) long. The fire-box had 7·14 square mètres of heating surface (76·5 square feet), and each of the compartments 16·66 square mètres (179 square feet), making a total of 73·78 square mètres (794 square feet). The experiments were made with coke and with compressed fuels, of which the Author selects the latter. The results are given in the following Table, in litres of water per square mètre of heating surface:—

Vacuum in Smoke-box. Centimètres of Water. = 0·39 inch.	Evaporation from Fire-box. Litres = 0·22 gal.	Evaporation from Compartments of Barrel.			
		No. I. Litres.	No. II. Litres.	No. III. Litres.	No. IV. Litres.
2	114·9	26·2	12·2	6·5	4·0
4	150·0	37·3	20·1	10·5	7·2
6	186·6	53·7	22·0	17·6	11·6
8	209·5	47·8	25·0	15·8	11·5
10	189·7	68·1	31·1	21·1	13·7

In the figures for 6 and 8 centimètres vacuum, there appears to be some error, as they conflict with each other. Making allowance for this, the Author deduces from the experiments the following empirical formulæ.

(I.) For the evaporation from the fire-box, per square foot of heating surface per hour,

$$F = 100 \sqrt[3]{v} + 16\sqrt{v} - 36,$$

where v is the vacuum in the smoke-box in centimètres.

(II.) For the evaporation from the tubes in any particular division of their length, per square foot of internal surface per hour,

$$s = \frac{25 + 32 \cdot 4\, v}{(1 \cdot 3 + 0 \cdot 05\, v + e)^2},$$

where e is the distance of the centre of the division from the fire box tube-plate, v the vacuum as before.

(III.) For the evaporation from the whole length l of the tubes,

$$R = \frac{25 + 32 \cdot 4\, v}{(1 \cdot 3 + 0 \cdot 05\, v)\,(1 \cdot 3 + 0 \cdot 05\, v + 1)}.$$

The Table and equations show clearly how large is the evaporation from the fire-box as compared with that from the tubes, and how rapidly the latter diminishes as the distance from the fire-box end increases; also how necessary it is, in calculating the evaporation of a locomotive, to take the length of the tubes into account. In a particular example, a reduction in the length of the tubes from 5 mètres to 3½ mètres (16 feet 4 inches to 11 feet 6 inches) would diminish the evaporation per lb. of fuel by about 6 per cent. On the other hand, it may be argued that to keep up a given vacuum in the smoke-box requires less steam with a short boiler than with a long one; and if so, the difference in economy between the two will be very slight. The Author considers that the maximum efficiency may be calculated by taking a vacuum of 12 centimètres (4·72 inches); and finds that, in the case of the eight-coupled locomotives of the Southern Railway of Austria, this gives a result of 48 litres per square mètre of heating surface per hour (0·16 cubic foot per square foot per hour), which agrees well with the results obtained with these engines in practice.

W. R. B.

On Locomotive Boilers.

(Zeitschrift des österreichischen Ingenieur- und Architekten Vereins, 1879, p. 153.)

In this Paper the Author considers the effect of the unequal expansion which takes place in a locomotive boiler, and the consequent movement of the parts relatively to one another.

The straining action on each of the different parts is minutely followed, and the cracks and deformations which usually appear are discussed in detail, and their causes traced; the fire-box and its tube plate being very exhaustively treated by the aid of drawings.

The Author, by the use of movable gauges, has succeeded in following experimentally the movements which take place, and,

amongst other results, he finds that the linear extension, in plan, of the inner fire-box is nearly all pushed out into the free corners by the constraining action of the stays; this distresses the plates, already injured at this place by flanging, and also bends the stays in the vertical rows nearest the corner. For stays at these and similar places, which are liable to be bent, the Author recommends a system of movable stays, particulars of which are given in the Paper; this system has already been for some time in use with good results.

The latter part of the Paper deals with corrosion and scale; their causes, and the influence upon them of local working and straining of the plates.

W. P.

Machines for Drilling and Screwing the Stay-bolt holes of Locomotive Fire-boxes. By F. Mathias.

(Revue générale des Chemins de fer, vol. i., p. 398.)

To supersede the tedious and laborious operations of drilling and screwing the stay-bolt holes of locomotive fire-boxes by hand, the portable cord system already employed in various ways for the transmission and application of power to distant points has been adopted in the workshops of the Northern Railway of France at Lille. Two upright 1-inch square bars are fixed, one at each angle of a wall of the fire-box, by supports which can readily be secured through rivet-holes or holes destined for stay-bolts. Two horizontal bars are sustained in guides attached to the uprights, and carry the drilling tool, which may be traversed horizontally on the bars, and so properly placed to drill each hole successively in a row. The horizontal bars or slides are raised or lowered to take each row successively, and thus the whole area of the plate becomes accessible to the machine.

The drilling tool is adjustable both horizontally and vertically, and is also fitted with a swivel motion, to enable it to drill holes at an angle in curved surfaces. The driving pulley, about 6 inches in diameter, is fixed on the drill-spindle. It is grooved for the driving cord, which is about $\frac{5}{16}$ inch thick, and it is supplemented by two small guide pulleys, which are adjustable, and by which the cord is properly directed to and from the pulleys.

The screwing tool is mounted like the drilling tool, and is provided, in addition, with wheel-and-pinion gear to multiply the power.

The total cost for mounting and for drilling by the cord system amounted in one instance to 0·63*d.* per hole, against 0·70*d.* by the ordinary system of transporting the work to the fixed radial drill. The special item of drilling is greater with the cord system than by the radial drill, but the excess is fully compensated by

the economy of time and labour in preparing and mounting the work. But, for screwing the holes, the cost by the cord system was only 0·45*d.*, against 0·72*d.*, the cost for screwing by hand, whilst the time occupied was only two-thirds.

D. K. C.

On the Cracking of Copper Fire-boxes, and the Furrowing of Shell Plates. By E. WEHRENFENNIG.

(Organ für die Fortschritte des Eisenbahnwesens, 1880, p. 9.)

The Author points out that if the fire-box and fire-box shell of a locomotive were only connected by the bottom ring, the effect of the heat would be to expand the former more than the latter, both because it is more exposed to the fire, and because it is made of a more expansible material, copper. Hence the distance between the two would be everywhere less when the engine was at work than when it was cold. The side and roof stays prevent this action in general; but they consequently intensify it in the parts which they do not protect, *i.e.*, at the corners of the fire-box between the outer rows of stays, which tend to be squeezed into folds or puckers. This puckering is the cause of the fine cracks which so frequently occur at these corners. By the use of a small measuring needle the existence of the puckering has been demonstrated in practice, to an extent of from 1 millimètre to 2 millimètres; and it is confirmed by the opening of cover plates on the riveted joints, by the cracking off of scale from the fire-door and tube-plate flanges, and by the rapid corrosion of the rivet and stay-bolt heads.

In the corner, between the tube-plate and side-plate, these cracks often occur in several parallel lines, especially opposite the caulking edge of the flange. They are assisted by the bellying outwards of the tube-plate under the internal pressure, and by the expansive force of the tubes, which also tends to form cracks round the tube ends. Where crown bars are used this action is intensified by the general expansion of the tube-plate itself, which can only take place internally, and thus tends to produce cracks round the tube-holes, especially near the sides and top.

These evil effects are mainly due to the row of stays nearest the corner, which resist the free expansion of the plates. Of course these stays are thereby themselves brought under a bending strain, additional to the direct strains which are due to the pressure of the stayed surfaces. The working of the bolts under this strain is the cause of the frequent cracking or breaking of these stays, and also of the corrosion which occurs in the shell-plates, sometimes in circles round the heads of the stays, sometimes in straight furrows from one stay to another. These straight furrows are only found at the outer rows of stays, and occur both with copper and iron stays.

The conclusion is that the present rigid stay-bolts should be

replaced, in the outer rows, by some form, capable of yielding to their particular strains, and thus allowing the free expansion of the corners. Several designs with this object are described, suitable to different situations; the principle in each case being to give the neck of the stay a rounded instead of a sharp angle, and to bed it in a cast-iron socket, similarly rounded; so that the stay is able to turn a little in its bearing, under a side strain, without losing its power of resistance in the direction of its axis.

W. R. B.

On the General Applicability of the Compound System to Locomotives. By E. Freytag.

(Organ für die Fortschritte des Eisenbahnwesens, 1880, p. 25.)

This is an elaborate inquiry, theoretical and practical, into the question whether the compounding of locomotives, as successfully introduced by M. Mallet,[1] really deserves to be universally applied. The conclusions at which the Author arrives are the following:—

(1). The system will be economical, so long as the content of the large cylinder is greater than the joint content of the two cylinders of an ordinary engine, and that of the small cylinder not less than that of one of those cylinders. If the dimensions fall short of these, the system will not be economical.

(2). The engine should never be run without compounding; as admitting steam direct to both cylinders would entail a great want of economy.

(3). For small engines and low speeds the system is easily applicable, and presents no disadvantages.

(4). With medium-sized engines the large size of the cylinders begins to be a serious evil. If they are put outside the frames, these latter must be made extra strong; since, even if the cylinders are so proportioned that with the ordinary load they do equal work, this will not be the case if the load is much greater or less than ordinary. Whether these objections are sufficient to prevent the compounding of such engines must be ascertained by practice.

(5). For heavy goods engines, &c., although economy of fuel is here of higher importance, the system is not to be recommended, even if the cylinders can be brought outside the frames without making the engine too broad. A cylinder of 30 inches diameter, with steam-chest, pipes, piston, and connecting rods, all on a corresponding scale, would be out of the question in the confined space of a locomotive. The only way to apply the system in these cases is by using four cylinders (two high- and two low-pressure), as already planned by M. Mallet.

In support of these conclusions the Author remarks, that the main advantages of the compound system are (1) its greater

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. li., p. 314; vol. lix., p. 349.

economy in steam, (2) the fact that the maximum pressure on the piston comes at a more favourable position of the crank than with ordinary engines. The latter, in high-speed engines, is very much neutralised by the action of the reciprocating masses; and the question of steam economy need therefore alone be considered. This is due, in the compound engine, to its higher grade of expansion, to the high-pressure cylinder being always kept at a high temperature, and to the steam being heated in the intermediate chamber. In order, however, that a compound may replace a simple engine, it must of course be capable of doing the same amount of work; and the Author therefore enters into a detailed calculation of the amount of work, both in starting and in running, developed by a simple and a compound engine respectively, of given dimensions. It is on this calculation that the first conclusion is based. In treating the work done by an ordinary engine, he assumes, as an inferior limit, that the mean pressure on the piston during the stroke is equal to 0·59 of the boiler pressure, which corresponds to a cut-off at about quarter stroke. Any earlier cut-off is rendered objectionable by the faulty distribution of steam, and the great back-pressure. The superior limit of work done does not depend on the cylinder, but on the supply of steam at high speeds, and on the adhesion at low speeds. With the compound engine, a cut-off at quarter stroke is again taken to give the inferior limit of work done; an earlier cut-off would give a bad distribution and an insufficient pressure for the blast. The superior limit is very high, if the direct admission of steam into both cylinders be allowed. This should only be permitted in exceptional cases, as at starting, since M. Mallet himself admits that it is unfavourable to economy. The result of the calculation is, then, to show a saving of fuel in running of about 24 per cent. in favour of the compound engine, together with a greater available power for starting, &c.; but only provided that the cylinder dimensions are as given in conclusion No. 1.

Another point to be considered is that of speed. With the light passenger engines on the Bayonne and Biarritz railway, the speed is assumed to be low. At high speeds there would be unsteadiness, from the want of balance in the reciprocating parts, the piston-rod, &c., of the large cylinder being much heavier than that of the small; and also from the fact that the cut-off must be earlier in the small cylinder than in the large, which, by means of diagrams and calculations, is shown to have a very unfavourable effect on the position of the periods of maximum pressure. This can only be remedied by making the cut-off in the large cylinder earlier at high speeds than at low. It is very important that means should be provided for cutting off at different points in the two cylinders when required.

W. R. B.

[1] [NOTE. An authentic description of this system, by M. Mallet, will be found in the Proceedings of the Institution of Mechanical Engineers, 1879, p. 328, in which it is stated that the speed rises to 30 miles an hour.—W. R. B.]

Canal Towing by Locomotives.

(Organ für die Fortschritte des Eisenbahnwesens, 1879, p. 197.)

Interesting experiments have lately been made on some of the French canals, with regard to towing barges by locomotives instead of by horses. A railway was laid down on the towing-path, about a yard from the brink of the canal, and a small locomotive of about 4 tons weight placed upon it. The wheels were coupled, and geared with a driving wheel making one hundred and forty revolutions per minute, and allowing a maximum speed of 7 miles per hour. The engine, which is worked by one man, was attached to a cable about 80 yards long, and then drew a team of barges with great success. It was found capable of drawing a net load of 100 tons of goods for each ton of its own weight. The actual speed was 2·4 miles per hour, and the average speed, allowing for stoppages, 1·8 mile per hour. With horses, the average speed is only 0·9 mile per hour; so that an important saving in time, as well as expense, appears likely to ensue. The system is to be tried on a large scale upon the canals between Dunkirk and Paris.

W. R. B.

On a Steam Tramway from the Hague to Scheveningen.

(Glaser's Annalen für Gewerbe und Bauwesen, 1879, p. 346.)

This tramway is about 3 miles long, and connects the Hague with the flourishing watering-place of Scheveningen. The Haarmann system was selected for the permanent way, on account of its great facility for laying on sharp curves, of which there are a large number on the line. The sleeper is longitudinal, and its section is that of a bridge rail, very much enlarged and opened out, and with the feet slightly bent over at the edges. The top is broad and flat, with a light feather along each edge; between these a Vignoles rail rests, and is held down by dog-headed clips hooked at the bottom. These clips are set opposite each other, and the hooks at the bottom are inserted in holes in the feet of the sleeper. A bolt passing through both clips and both sides of the sleeper tightens all up. The vertical sides of the sleeper of course enable it to be bent to a curve without difficulty, which is not the case with the gutter-shaped section of Hilf and others. On the Scheveningen line the dimensions of the rail and sleeper were adapted for a load of 5 tons on each wheel. The rails are jointed with steel fish-plates and bolts. The joints of the sleepers coincide with those of the rails: the ends of the two sleepers rest on a cross-sleeper, of the same section, but turned on its back, and having the bent edges of the feet cut away, where it passes under the longitudinals.

A cast-iron junction-piece fits under and is bolted to the feet of the longitudinals, and also bears on the cross-sleeper, thus conveying the load from one to the other. In addition to these cross-sleepers, a tie-bar, passing through the vertical sides of the longitudinal and tightened up with a nut at each side, is introduced in the middle of each rail length of 24 feet 7 inches. On curves this tie-bar is replaced by a second cross-sleeper. Where the tramway is laid along paved streets, a guard rail is laid along the inner side of each rail, leaving an interval of $\frac{7}{8}$ inch, and secured to it by bolts and cast-iron distance pieces. As the height from the top of the rail to the upper surface of the sleeper foot is 6 inches, the first row of paving stones rests conveniently on the sleeper foot, and there is thus no possibility of their sinking below the level of the rail.

In laying the line the rails were supplied from the works ready bolted to the sleepers, and both bent, where necessary, to suit the curves, of which the sharpest has 92 feet radius. The rails weighed 39 lbs. per yard, the sleepers 32 lbs.; and the total weight of the track was 162 lbs. per yard on the open road, and 190 lbs. in paved streets.

The engines used are Merryweather's tramway locomotives, 7-inch cylinders, 11 inches stroke, working pressure 120 lbs. Twelve of them are now working with success. The rolling stock consists of long double-bogie carriages, ordinary four-wheeled carriages, and light open goods wagons. Drawings of all these are given. The tramway has been open since June 1879, and has been very largely used, running at the busiest season sixty-four trains daily.

W. R. B.

Warming Railway Carriages in France. By J. B. Personne.

(Revue générale des Chemins de fer, vol. i., p. 181.)

This Paper is devoted to a consideration of the means of replenishing or re-heating foot-warmers on railways in France. Portable foot-warmers are re-heated by the injection of steam of high pressure, or by immersion in boiling water. Fixed warmers —such as are let into and fixed to the floor of the carriage—are treated by the circulation of hot water.

For heating foot-warmers by high-pressure steam, the steam is distributed to a number of tubes, which may be moved up or down by hand in a suitable framework, in order to enter the ends of a corresponding number of foot-warmers respectively, into which the steam is to be injected, and which are carried in a three-wheel truck, or tricycle, specially constructed, moved on rails. Before being placed under the apparatus, the warmers are nearly filled with water, leaving a small space for the con-

densed steam. In two or three minutes the temperature may be raised to 195° Fahrenheit; the main steam-cock is closed, the tubes are lifted, the truck with its load is withdrawn, and the foot-warmers are plugged up and placed in the train. On the Orleans railway, apparatus of this kind has been at work at twenty-one of the principal stations, since October, 1876; there are about eleven thousand foot-warmers in the service. An injection-apparatus for a large station costs £78; a tricycle complete, £14; a foot-warmer, 16*s.* to 17*s.* 6*d.*; a steam-boiler for one apparatus, £158. The foot-warmers of the Northern railway, heated on the same system, weigh, empty, 29 lbs., and hold $1\frac{3}{4}$ gallon. In raising the temperature from 60° Fahrenheit to 195° Fahrenheit, $2\frac{1}{4}$ lbs. of steam are consumed. The expense for re-warming, at the Paris station, is $\frac{1}{3}$*d.* per foot-warmer.

On the second system, by simple immersion, without either opening or closing the foot-warmer, it is plunged into a bath of hot water. It has been determined experimentally that an ordinary metallic foot-warmer, filled with water at 32° Fahrenheit, properly plugged, and immersed in hot water maintained at the temperature 212° Fahrenheit, is raised to the temperature 195° Fahrenheit in five minutes. The hot water is contained in a circular sheet-iron bath of considerable depth, sunk into the ground, in which a noria circulates, letting down the foot-warmers and elevating them successively. The temperature of the baths is maintained by steam delivered through pipes. The noria holds twenty-four foot-warmers at a time; and, allowing five minutes for immersion, there are heated two hundred and eighty-eight foot-warmers per hour. The quantity of steam, at $3\frac{1}{2}$ atmospheres, consumed, amounts to $4\frac{1}{2}$ lbs. per foot-warmer. The total cost, including interest, &c., amounts to $\frac{1}{2}$*d.* per foot-warmer placed in the train. The foot-warmers are oval in section, 3 inches by 8 inches, and 3 feet long; of tinned iron, $\frac{1}{16}$ inch thick, weighing $17\frac{1}{2}$ lbs. empty, and holding $17\frac{1}{2}$ lbs. of water; and cost 14*s.* 6*d.* each.

On the Eastern railway a third system is practised, a small cast-iron furnace is fixed to one side of the carriage. It is fed with coke from the top, and is surrounded by water, which is heated, and conveyed by circulating pipes through foot-warmers of cast iron let into the floor of the carriage. Each foot-warmer exposes a radiating surface, 8 inches wide and $7\frac{1}{2}$ feet long. On this system, a temperature of from 120° to 140° Fahrenheit is maintained under foot, whilst the general temperature is maintained 18° or 20° above that of the external air. It has been at work during the winters of 1876–78, and it is much in favour with passengers. The cost for fuel is at the rate of about $\frac{1}{2}$*d.* per hour on the journey, for one third-class carriage of five compartments. The total cost, including interest, &c., amounts to 2·85*d.* per carriage per hour.

D. K. C.

Pneumatic Propeller for Railways. By L. Gonin.

(Bulletin de la Société Vaudoise des Ingénieurs et des Architectes, vol. v., p. 53.)

The Author describes a new form of valve and piston carriage for the tube of a pneumatic railway. It is proposed to use air compressed to 6 atmospheres, and to apply the system, on grounds of economy and safety, to lines having heavy gradients and but little level track. The tube is of cast iron provided with numerous exterior stiffening ribs, and fixed upon cross sleepers between the ordinary rails, the latter being laid on longitudinal resting on the transverse sleepers. The slot in the upper part of the tube is bevelled on its interior edges, thus forming a seating for the continuous valve. The valve, made of greased leather wrapped round a wooden body and having an iron band above and below, is in the form of a truncated wedge with the narrow end upwards, so that the pressure of the air within the tube may press the valve tightly into the wedge-formed sides of the longitudinal slot. The valve, when not pressed upwards by the air, hangs within the tube from a continuous flat band of iron, wide enough to overlap the slot in the tube, and to rest on the edges of the slot. Both iron band and valve are sufficiently flexible, their connection at a distance of some inches by bolts not materially affecting this quality. When the valve is in mid-position, vertically, so that the valve is clear below its seat, and the iron band is clear above the upper edge of the slot, there is room on each side of the connecting bolts for the passage of a double coulter piece, connecting the piston in the tube with the carriage above, which is driven by it. The part of the valve at and behind the piston is kept up in its highest position by the compressed air, while the part ahead of the piston falls to its lowest position. The carriage driven by the piston carries in front a small wheel which runs upon and presses the iron band down, and thus regulates its position for the passage of the coulter. The coulter may be either attached to a large vehicle or, by the Author's preference, to a small chariot running on separate rails on the top of the tube, and drawing its load by chain connection, or the load may be pushed by a buffer. The corresponding buffer, which would be carried by the engines on a line employing the compressed-air system for helping trains up heavy gradients, is made to rise and fall so as to clear the chariot until beyond it. It is then dropped, and the chariot brought into work. The arrangement of valve described differs entirely from those of Clegg and Samuda employed on the atmospheric and pneumatic railways, and it affords a tight joint, while it has not to be raised by, nor is it exposed to any wear by, the coulter. The latter is moreover double, one-half passing into the tube on either side of the valve, the strains upon it being thus of a simple order.

As the quantity of power required for compressing air does not

increase with the increase of pressure, but in proportion to the logarithm of the pressures, the Author proposes pressures as high as from 6 to 10 atmospheres, so that the air may be employed expansively, the full pressure being used for starting and travelling the greater part of the journey on inclines; the air would then be cut off, and the remainder of the journey performed by expansion. An experimental length of tube, 10 inches in diameter and 131 feet in length, has been constructed, the results of experiments with which are given.

W. W. B.

On the Efficiency of Coating for Steam Pipes.

By M. Walther-Meunier.

(Bulletin de la Société industrielle de Mulhouse, 1879, p. 730.)

Three series of experimental trials of various non-conducting substances for coating steam-pipes of cast-iron, wrought-iron, and copper, were conducted by M. Walther-Meunier, in a locality of which the temperature was uniform, or nearly uniform, at the works of Messrs. Schlumberger, Sons, & Co., Muhlhausen. The trial pipes were each 98½ inches long between flanges, and 5·91 inches in diameter. Steam from a boiler was admitted into them, and the condensed steam was collected in a worm immersed in cold water, by which the whole of the condensed steam was retained.

The naked pipes were exposed, with the following results: the compositions are, for the most, distinguished simply by the names of the manufacturers:—

		Cast Iron.	Wrought Iron.	Copper.
Difference of external and internal temperatures	Fahr.	226°	222°	227°
Steam condensed per hour . . .	lbs.	13·47	13·50	10·69

The performances of the most efficient coatings were as follow:—

Best Results.		Cast Iron.	Wrought Iron.	Copper. (Asbestos.)
Difference of temperatures . . .	Fahr.	234°	217°	229°
Steam condensed per hour . . .	lbs.	6·01	5·24	7·00

But few data are given by which comparisons may be drawn. Leroy's composition was applied to wrought-iron and to copper pipes:—

Leroy.		Wrought-iron Pipes.	Copper Pipes.
Difference of temperatures . . .	Fahr.	231°	234°
Steam condensed per hour . . .	lbs.	7·10	8·21

It is remarkable that the copper pipe, whilst it condenses less steam than cast-iron pipe or wrought-iron pipe when naked, condenses the greatest quantity of steam, comparatively, when covered.

D. K. C.

Reports of the Alsatian Association of Steam Users 1878–79.

(Bulletin de la Société Industrielle de Mulhouse, 1879, p. 709.)

At June 30, 1879, there were 1,561 boilers enrolled and under the inspection of the Association. Of these, 52 per cent. were at work in spinning and in weaving-mills, and 18 per cent. in metallurgical establishments. The "elephant," or heater boiler, continues to be used to the extent of 80½ per cent. of the total number enrolled; whilst inside-flue cylindrical boilers amount only to 4⅓ per cent. Sectional boilers of various kinds, taken together, amount to just 3 per cent. The following is a general classification of the 1,561 boilers:—

				Per Cent.
Kettle boiler (chaudière à tambour)			1	
Plain cylindrical boilers			74	or 4·74
Elephant boilers	1 heater	70		
	2 heaters	468	1,257	„ 80·53
	3 or more heaters	719		
Inside-flue boilers	1 flue	20	68	„ 4·38
	2 flues	48		
Tubular and semi-tubular boilers			55	„ 3·54
Portable, semi-portable, locomotive, steamers			59	„ 3·73
Various boilers (Belleville, Sinclair, Field, La Chapelle, de Naêyer)			47	„ 3·08
Total			1,561	100·00

Of these boilers, 47 per cent. are supplied with feed-heaters, three-eighths of which consist of Green's economisers. Six boilers are upwards of 45 years old; 50 boilers are upwards of 35 years old; 170, or 11½ per cent., are upwards of 25 years old; 656, or 45 per cent., are upwards of 15 years old; two-thirds of the total number are upwards of 10 years old, and one-third do not exceed 10 years of age.

Of the failures that had been recorded during the year, 1,808 in number, or a little more than 1 per boiler, 30½ per cent. were due to neglect of maintenance and cleaning-out; 29 per cent. took place in the furnaces and the brickwork; 14½ per cent. were failures of the plates, and 9½ per cent. were failures of the connections;

13 per cent. were caused by corrosion, about equally inside and outside.

Check-valves between the boiler and the feed-heater are considered to be indispensable for the prevention of accidents. The magnetic water-level indicators of Messrs. Lethuillier and Pinel, constructed by them, have given satisfaction; but, since the expiration of the patent, magnetic indicators have been manufactured by others, and it has been observed that many of these have failed. The asbestos-packed cocks of Messrs. Dewrance & Co. have given great satisfaction.

D. K. C.

Experiments on the Action of Fats and Mineral Lubricants on Iron, in the presence of High-Pressure Steam.

(Mittheilungen aus dem Gebiete des Seewesens, vol. vii., p. 523.)

It is well known that steam of high temperature decomposes natural fats, and causes free acids to separate from them. When used as lubricants, in cylinders employing high-pressure steam, the resulting acids corrode the metal surfaces with which they come in contact. With steam of very high pressure, this takes place with great rapidity; with steam of medium pressure it continues, though to a less degree; but it goes on also even in the damp atmosphere, as is proved by fats turning rancid when exposed to the air. In engines provided with surface condensers, the result may be serious injury to the boilers; for the fats carried away from the cylinders with the exhaust steam, are returned to the boilers in the feed-water, and are there decomposed. The continuous action of hot steam causes also the generation of volatile acids, which leave the boiler with the steam, and injuriously affect steam pipes and cylinders. In this way the speedy destruction of boilers fed from surface condensers is generally accounted for. Some persons attribute this destruction, to a certain extent, to the use of distilled feed-water. In consequence of all this, mineral oils, which consist chiefly of hydro-carbons, and which do not suffer decomposition at the ordinary temperature of steam-boilers, have come into use, although as lubricants they are far from efficient at high temperatures. One circumstance should, however, be mentioned, which somewhat diminishes the usefulness of mineral oils, viz., at high temperatures mineral oils adhere to the sides of the cylinders less than water does, and consequently, when steam is shut off, the condensed water rusts the surfaces more than it would do, were animal fats used. The following experiments were all made in consequence of the remarkable results given by the following analysis of the sediment deposited in the surface condenser,

—	I. Deposit from Condenser.	II. Deposit from Cylinder.	III. Deposit from Boiler.
	Per cent.	Per cent.	Per cent.
Water	10·59	0·23	0·88
Mineral oil	36·29	18·43	1·50
Fatty acids	24·19	2·70	0·58
Neutral fats		2·14	0·12
Copper (In the metallic state)	1·78	2·11	..
Lead (In the metallic state)	1·08	0·50	..
Zinc (In the metallic state)	0·30	0·40	..
Iron (In the metallic state)	7·37	21·44	..
Oxide of iron	16·0	46·58	74·26
Peroxide of iron	..	..	14·68
Gypsum	0·32	trace	5·34
Salt, common	0·74	trace	1·93
Organic dirt	2·98	2·58	0·58
Inorganic dirt	1·79	2·89	trace

cylinder, and boilers of a marine engine. The lubricants used were, first, tallow, and then, till the day of the experiments, mineral oil. The metal found in the deposit existed in the state of very fine dust, which preserved its metallic brightness perfectly. The iron was in such a minute state of subdivision that, after separation from the compound, it burnt spontaneously with a bright red heat on exposure to the air. These particles of metal were of course produced by the friction of the piston, &c., and it is a matter of special importance to observe that, in spite of their minute subdivision, and prolonged exposure to the oxidising influence of water and steam of high temperature, they were, nevertheless, perfectly free from oxidation. Apparently the remains of the lubricants had preserved them; and hence the question arises—in opposition to the commonly received views—to what extent do these residues of the lubricants preserve metals from the oxidising influence of water and steam?

To solve this question, a strong copper boiler was made use of, connected by means of a pipe with a receiver, having a screwed top. Into the receiver were placed small vessels, which contained the metal plates and the different lubricants to be experimented upon; so that any differences in the corrosion of the plates could only be ascribed to the action of the lubricant. The pressure in the boiler was maintained at from two to three atmospheres above the air pressure. The test-plates were accurately-weighed pieces of boiler plates, which, after the experiments, were thoroughly cleaned and again weighed. The difference in the weights gave the amount of iron lost by oxidation. The experiments were made with both sea and distilled water. The plates were half immersed in the water, their surfaces having been painted with the lubricating material, a little of which was also poured

on the surface of the water. The following Table gives the results:—

Number.	Length of Experiment. Days.	——	Weight of Plate in Milligrammes. = 0·0154 Grain. Before the Experiment.	After the Experiment.	Loss of Weight in Milligrammes.
1	2	In sea water	32564·0	32519·0	45·0
2	2	" " with tallow . . .	32386·0	32375·0	11·0
3	2	" " " mineral oil .	29961·5	29954·5	7·0
4	6	" " (no lubricant) . .	32228·5	32050·0	178·5
5	6	" " with tallow . . .	32198·5	32171·0	27·5
6	6	" " " mineral oil .	29814·5	29796·0	18·5
7	6	In distilled water	31907·0	31867·0	40·0
8	6	" " with tallow . .	32126·0	32115·0	11·0
9	6	" " " mineral oil	29751·0	29734·0	17·0
10	6	" " (no lubricant) .	29693·5	29652·0	41·5
11	6	" " with tallow . .	31775·5	31764·0	11·5
12	6	" " " mineral oil	32066·0	32050·5	15·5

Experiments 1 to 6 prove that sea-water alone and its steam destroy iron more rapidly than when tallow and mineral oil are present. The tallow, when fresh, contained 0·4 per cent. free acid, and after six days' exposure to steam, 3·4 per cent. Experiments 7 to 9 prove the same thing with regard to distilled water, and prove also that distilled water is less harmful than salt water. In experiments 10 to 12 the plates, which were before exposed to the pure distilled water, were now coated with the lubricant, and *vice versâ*, but without altering the result.

The oft-observed fact, that boilers of engines provided with surface condensers have a very short lifetime, must therefore be ascribed to some other effect of the lubricating material than the generation of acids, for it has been proved above that, in spite of the presence of acids, the lubricants tend to preserve the plates from rust.

The following reason is advanced by the Author to account for the destruction of the boilers, no account being taken of the direct action of the acids. When the lubricants come into the boiler, and acids are formed, these latter, acting on the lime and other alcalic minerals in the feed water, form insoluble soaps, which are deposited on the sides and bottom of the boiler, furnaces, &c. Furthermore, the fatty acids, acting on the oxide of iron contained in the feed-water, or existing on the boiler-plates, form insoluble iron soap, which also is deposited in a similar manner. These soaps are non-conductors, and in consequence the plates which are covered by them, and which are also exposed to the action of the fire, are overheated, and rapidly destroyed. An illustration

of this action may be obtained by boiling sea-water in a platinum basin, over a moderate steady flame. Under these circumstances the boiling proceeds quite quietly. Let now a few drops of an oil rich in acids be dropped on the water; after a few moments the steady boiling ceases, and violent ebullition and foaming takes place. The bottom of the basin will be found to be covered with a thin layer of soap, which the water cannot touch.

The Author carried out a series of experiments to determine the relative values of tallow and mineral oils as preservatives for iron, under conditions which obtain in boilers. The result was that the mineral oils proved incomparably the best. When tallow is used, the result is satisfactory for the first few days, but as the formation of acids steadily progresses, so the oxidation rapidly increases. As a result of his researches, the Author recommends that, wherever the lubricating qualities of mineral oils suit the circumstances, they should be used with engines provided with surface condensers; but in the case of ordinary condensers, and non-condensing engines, tallow may be used without any ill effect, as it passes through the cylinder before there is time for acids to form, and consequently the metal surfaces are not exposed to any injurious action.

G. C. V. H.

Comparative Experiments on Single-Cylinder and Woolf Beam Engines. By O. Hallauer, with report on, and summary of, this memoir by M. Keller.

(Bulletin de la Société Industrielle de Mulhouse, 1879, pp. 209–320.)

The Author commences by stating the conclusion at which he arrived some time since, that it is always possible to construct a beam engine having one cylinder and four valves, working with saturated steam, cutting off from $\frac{1}{4}$ to $\frac{1}{7}$ of its stroke, steam-jacketed, and having clearance space of not more than 1 per cent. of the cylinder volume, which shall be at least as economical as a compound ("Woolf") beam engine of the same power. His Paper is devoted to a proof of this proposition by a detailed analysis of several trials of engines of the two systems, most of which have been already published in the Bulletin of the Industrial Society of Muhlhausen. In each case he analyses, by the method described in a former memoir of his own,[1] the consumption of heat, the results

[1] Moteurs a vapeur, expériences dirigées par M. G.-A. Hirn, exécutées en 1873 et 1875 par MM. Dwelshauvers-Dery, W. Grossteste, et O. Hallauer. (Presented to the society October 1876, and published separately by Gauthier Villars, of Paris.) This memoir, it may be mentioned, is indispensable to the complete understanding not only of the paper here summarised, but of other papers on similar subjects frequently published by the same society.—A. B. W. K.

obtained by direct measurement of the feed, and by measurement of the condenser discharge checking each other throughout, the mean error being only 1·75 per cent. The annexed Table gives a summary of the principal results of his investigations. The last column in this Table needs the explanation that by "absolute"

Engine.	Ratio of Expansion.	Indicated HP.	Consumption of dry saturated Steam per Hour.		
			Indicated HP.	Effective HP.	Absolute HP.
Woolf beam engine at Munster, made by Koechlin . . .	9 : 1	347	18·98	21·74	15·67
Ditto	7 : 1	267	19·27	22·85	15·30
Ditto	7 : 1	185	21·45	27·35	·6·27
Ditto do. at Malmerspach, same maker	6 : 1	202	19·51	22·71	16·31
Ditto	13 : 1	215	17·96	20·85	15·17
Ditto	13 : 1	213	18·10	20·99	15·39
Ditto	28 : 1	143	18·23	22·06	14·84
Ditto	25 : 1	149	18·21	21·82	15·04
Horizontal Woolf engine, same maker	6 : 1	130	20·11	23·22	16·07
Ditto	6 : 1	181	19·58	21·98	16·14
Woolf beam engine, made by T. and T. Powell	19 : 1	137	19·73	21·39	15·08
Horizontal Corliss engine, steam-jacketed (Berger, André, and Co.)	11 : 1	105	17·59	20·00	15·85
Ditto	8 : 1	137	17·50	19·22	15·96
Ditto	6 : 1	158	17·53	19·07	16·11
Hirn's single-cylinder beam engine, unjacketed . . .	7 : 1	107	19·49	21·89	17·24
Ditto	4 : 1	146	20·52	22·78	18·63
Ditto	7 : 1	113	16·25	18·05	14·66
			Steam superheated to 385° Fahr.		
Ditto	4 : 1	154	16·82	18·10	15·43
			Steam superheated to 447° Fahr.		
Ditto	2 : 1	125	19·07	20·97	17·35
			Steam superheated to 523° Fahr.		

HP. the Author means the HP. which would have been developed had the engine been working with a perfect condenser, the steam line of the indicator diagrams remaining as it actually was, but the exhaust line being supposed to be horizontal and coincident with the zero line or line of no pressure. This method of comparing results is adopted in order to make it possible to compare what may be called the "cylinder economy" of steam in the different cases, as distinct from the effect caused by a better or worse condenser, which might be used with any type of engine, simple or compound.

The Author also gives the results of some investigations into the comparative effects of throttling the steam and using a cut-off valve.

The following are the principal conclusions at which M. Hallauer arrives:—

(i.) In a Woolf engine, working at about half its full power, and with a boiler pressure of, say 5·5 atmospheres, it is possible to obtain, in practice, a saving of about 10 per cent. of steam, but cutting off earlier in the high-pressure cylinder instead of throttling the steam.

(ii.) In the same engine, however, when working at full power, a difference of 10 per cent. in power can be effected by throttling without altering sensibly the steam economy.

(iii.) In a single-cylinder (Corliss) engine, steam-jacketed, there is in practice a saving of about $4\frac{1}{2}$ per cent. by working with a six-fold expansion as compared with an eleven-fold expansion.

(iv.) In a single-cylinder beam engine, unjacketed, and working with either superheated or saturated steam, there is in practice a gain of about 4 per cent. in working with seven-fold expansion as compared with four-fold. An experiment with superheated steam showed a difference of 15 per cent. in economy between a cut-off of $\frac{1}{2}$ and of $\frac{1}{7}$.

(v.) As comparing the two types of engine, single-cylinder and (Woolf) compound, there is in most cases a theoretical economy of about 4 per cent. in favour of the latter, in consumption of steam per HP. absolute. But the effect of the loss between the cylinders and of the greater friction in the double-cylinder engine is to change matters altogether when the comparison is made of the consumption of steam per HP. effective, in which respect the Corliss engine has an advantage of about 9 per cent.

In working out his results the Author makes much use of a quantity which he calls Re, "le refroidissement au condenseur," and which greatly assists the comparisons he makes. It may be well to explain that this quantity stands for the excess of the heat taken up per stroke by the cylinder walls over that necessary to supply the loss of internal energy from the steam during expansion, including in this loss the work done after cut-off. This amount of heat passes to the condenser at each stroke, and affects the working of the engine by raising the back pressure, &c.

A. B. W. K.

Steam Fire-Engine Trials. By Dr. E. Hartig.

(Civilingenieur, vol. xxv., p. 497.)

In this paper details are given of a competitive trial made at Leipzig between a fire-engine, constructed by G. A. Jauck of that place, and one by the Silsby Manufacturing Company of Seneca Falls, New York. The American machine consisted of a rotary

engine coupled directly to a rotary pump; the principal dimensions and results for this were:—

Grate surface	6 square feet.
Heating surface	170 "
Water in boiler	25 gals.
Time required to get up 3 at. steam	8 min. 49 secs.
Water evaporated per lb. coal (Zwickauer)	4·48 lbs.
Pressure in air vessel	7·66 at.
Pressure in boiler	4·02 at.
Quantity pumped per minute	139 gals.
Revolutions per minute	271
Indicated HP.	14·9
Effective HP. utilised in pump	10·4
Efficiency $= \frac{10 \cdot 4}{14 \cdot 9}$	0·70
Slip in pump	14 per cent.
Weight of fire-engine complete	2½ tons.

The German machine had rotative engines driving bucket and plunger pumps, but the results obtained were inferior to the above, 64 per cent. of the indicated HP. being absorbed in friction. The Paper also contains a notice of the performance of the Silsby fire-engine at Philadelphia, and a description of the fire-engines built by the Lausitzer Maschinenfabrik to designs by Prof. Bach, of Stuttgart.

W. P.

Steam- or Compressed-Air Winch for Winding.

(Annales industrielles, 1879, col. 468.)]

A winch, capable of being worked either by steam or by compressed air, is at work at the Saint-Etienne collieries. It was designed for simplicity, security, and regularity of action, being controlled by a governor, by which the rate of speed of winding or unwinding of the rope cannot exceed 3 feet per second. The engine, consisting of two horizontal cylinders, fixed on the outer sides of the frame, moves uniformly in one direction, and turns the barrel or roller by means of spur-gearing. The gearing is in duplicate, and may be driven either at one side or the other by means of alternative friction-drums; but the gearing at one side is fitted with an intermediate wheel, by means of which the motion of the roller is reversed as compared with the motion when it is driven by the direct gear at the other side. By means of a sliding clutch, either friction-drum may be put into gear; and when the lever is upright, and the clutch is placed midway, the whole of the gearing is free, and the roller is at rest. The roller is made in two lengths, right and left, for the winding ropes, having the driving spur-wheel fixed between them. The speed is controlled by a centrifugal governor. The governor consists of a number of weights installed

in a cellular cylinder, of which the cells are sectoral, and are open at the circumference, and which revolves within a circular box fixed to the frame. At ordinary speed, the weights are kept in place, each in its own cell, by a circular spring which surrounds the revolving cylinder and moves with it. When the speed becomes excessive, the weights by their centrifugal force drive out the spring, and force it against the inside of the fixed cylinder. The frictional resistance thus set up between the spring, which is covered with leather, and the box, suffices to moderate and to control the speed as required.

D. K. C.

Plain Coupling for Shafts.

(Bulletin de la Société Industrielle de Mulhouse, 1879, p. 842.)

M. E. Comte, of the house of MM. Munier and Prévost, at Albert, Somme (France), describes a safety-coupling which is free from keys, set-screws, and bolts and nuts. The coupling consists of a plain hollow cylinder, cut longitudinally in two halves, laid upon the adjoining ends of the shafting, and bound together and to the shaft by two wrought-iron rings shrunk upon them. The coupling is bored out to a diameter a trifle less than that of the shafting; at the same time, the two halves are each a trifle less than a semi-cylinder, in order to avoid contact between them, and that they may firmly seize the shafting. The ends of the shafting are unpolished, just as they leave the lathe. By means of this coupling, when carefully constructed and applied, any degree of force can be transmitted with certainty.

The length of the coupling is five times the diameter of the shaft; the thickness at the middle is 0·60 of the diameter, and at the ends 0·55 of the diameter; the thickness of the shrunk rings—of Swedish iron—is 0·30 of the diameter, and the width is 0·90 of the diameter. For a shaft 2 inches in diameter, the length of coupling is 10 inches; the thicknesses 1·20 inch and 1·10 inch; the rings are 0·60 inch by 1·80 inch. A table of dimensions and weights is given.

D. K. C.

Turbines on the Aar, at Berne.

(Annales Industrielles, 1879, col. 523.)

Two large Jonval turbines have been constructed to replace twenty-four water-wheels on the Aar, for the service of the greater number of the small factories on the banks of the river, and of several large mills at Berne. The canal, or conduit on which the water-wheels are ranged, is utilised for the turbines. The turbines

give motion to a line-shaft which reaches the whole length of the canal, turning day and night, and from which the power is taken for each factory.

The conduit by which the water is admitted to the turbine is $12\frac{3}{4}$ feet wide, and averages $7\frac{1}{4}$ feet deep. The water is delivered at the rate of 464 cubic feet per second, at a speed of about 5 feet per second. The fall varies from $6\frac{3}{4}$ feet to $7\frac{1}{2}$ feet. Each of the turbines is constructed for a discharge of 216 cubic feet per second, and for a minimum fall of $6\frac{3}{4}$ feet; so that the two together produce 234 HP. of useful work, on a coefficient of 70 per cent. The external diameter of the wheels is $11\frac{1}{2}$ feet; they make twenty-six revolutions per minute. There are thirty-six guide-blades, and thirty-six vanes or blades in the wheel. The pivot is of hard cast-iron, 6·30 inches in diameter; it supports a gross load of 16·1 tons, being at the rate of about 1,150 lbs. per square inch.

D. K. C.

Experiments on the Theory of the Reaction Turbine.

By A. Fliegner.

(Zeitschrift des Vereines deutscher Ingenieure, 1879, col. 459.)

In the theory of the reaction or full-turbine, it has been hitherto assumed that the water elements are steadily guided and follow curves congruent with the vane curves. The resistance to the passage of the water is consequently estimated as due, partly to the sudden deviation of the direction of the water in passing from the guide passages into the wheel, partly to the friction of the sides of the wheel passages. But the assumption that the water is completely guided is only true for infinitely numerous vanes. When the number of vanes is small and the width of the passages proportionately great, only a small fraction of the water is directly guided, and that only on one side. The other parts may follow paths differing indefinitely from the path of the vanes.

The only experiments on the resistance in passages similar to those in turbines are two made by Weisbach. The Author discusses these fully, and shows that they are inconsistent with the theory that the resistance is due to the causes mentioned above. As there were no other experiments, the Author undertook a series of experiments, in number more than one thousand, on a set of wheel passages and guide passages of small size. Nine wheel passages were constructed, with an opening at the entrance of about 15 millimètres by 30 millimètres (0·60 inch by 1·2 inch), and having various angles at the points of entrance and discharge. To these could be accurately fitted six passages representing the guide passages. The difference of pressure at the points of entrance and discharge from the wheel passages was measured by a manometer and varied from 1 to 30 mètres (3 to 100 feet)

of water. The discharge with each pressure was also measured, and this, divided by the measured areas of the passages, gave the required velocities. As the individual results are too numerous to tabulate or discuss, the Author gives a series of values for regular intervals of pressure, obtained by graphic interpolation.

Let h be the total difference of pressure producing flow through the wheel passage; c_2 the velocity of discharge (relatively to the wheel considered at rest), then—

$$h = (1 + \zeta) \frac{c_2^2}{2g}.$$

Where ζ is the coefficient of resistance of the passage. The values of ζ obtained by interpolation from the experiments are given for all combinations of the wheel and guide passages.

In calculations on turbines it is necessary to express ζ as a function of the circumferential velocity of the wheel, the variation of which causes a variation in the angle at which the water enters the wheel. Let c be the absolute velocity of discharge from the guide passages, a the angle between its direction and the normal to the dividing plane between the guide passages and wheel; w the circumferential velocity of the wheel at the point where the water enters. Then the resultant c_r in a direction inclined at a_r to the normal is the relative velocity of the water and wheel. Then ζ has a minimum value for some value a_o of a_r, which is the most favourable angle for the admission of water to the wheel. On either side of this value of a_r, ζ increases in a curve approximately parabolic. Putting ζ_o for the minimum value of ζ

$$\zeta = \zeta_o + \mu (\tan a_r - \tan a_o)^2.$$

Throughout the experiments the most favourable direction of the relative velocity is found not to agree with the tangent to the wheel-vanes, as hitherto it has been supposed that it would do. This deviation is due to the peculiar contraction of the stream, which, with the theoretical direction of entrance, permits greater expansion of the stream than with a somewhat different direction. The Author then finds empirical expressions for a_o, μ, and ζ_o.

Assuming these three constants determined for any turbine, the pressure height lost in overcoming the resistance in the wheel is—

$$h_w = \left[\zeta_o + \mu \left(\frac{w}{c \cos a} - \tan a - \tan a_o\right)^2\right] \frac{c_2^2}{2g},$$

This is the quantity to be substituted in Redtenbacher's theory for the terms expressing the shock at entrance and friction of passages.

The numerical values given in the Paper are so numerous that no abstract of them likely to be useful could be made short enough to be inserted here.

W. C. U.

Portable Band-Saw Driven by Water-Pressure.

(Die Eisenbahn, vol. xii., p. 10, and Bull. de la Société d'Encouragement, 1879, p. 653.)

[In the discussion on Mr. Robinson's Paper on the transmission of power to distances, reference was made[1] to the small portable hydraulic engines used in the streets of Zurich and other Swiss towns for sawing wood, &c. The following particulars refer to one of the latest arrangements of Hr. A. Schmid, of Zurich, the maker of most of the machines in question.]

On a light four-wheeled truck is mounted a platform, horizontal for two-thirds of its length, to which is attached the band-saw frame, the driving pulley being situated underneath the table, between the wheels of the truck. The fore-part of the platform is bent downwards, at an angle of about 45°, and carries the water-pressure engine, which transmits its power to the saw pulley by a band taken off the fly-wheel. The engine-bed being thus inclined, its weight bears directly on the leading wheels of the truck, without any overhang, thus balancing the saw-frame and securing compactness and stability. The diameter of the cylinder is 3·15 inches; length of stroke 4 inches. With a pressure due to a head of 196 feet of water the engine makes one hundred and eighty revolutions a minute, consuming 1 litre (0·0353 cubic foot) per revolution. The speed of the saw pulleys is 2·77 times that of the engine. The feed is obtained by a flexible hose, which can be coupled to cocks in the street mains, and a similar hose attached to the engine conveys the exhaust into the gutters. The whole weight of the machine is only 970 kilograms (1,914 lbs.). The water is sold to the proprietors of these portable saws at the rate of $2\frac{1}{4}$*d.* per cubic yard, the consumption being at the rate of 6 to 10 cubic mètres (1,320 to 2,200 gallons) per hour. The consumption is measured by means of a counter attached to the engine, which records the number of revolutions made.

Hr. Schmid has also constructed a portable turbine for driving a Gramme dynamo-electric machine to supply electric light in any quarter of the town, for out-door work, or for public fêtes.

F. G. D.

On the Employment of the Injector as a Motor for Hydraulic Lifts. By Hr. Othegraven.

(Organ für die Fortschritte des Eisenbahnwesens, 1880, p. 6.)

The Author remarks that the advantage of using hydraulic power for the lifting of heavy weights through short distances has long been recognised; but an important objection is the necessity

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlix., p. 34 *et seq.*

of special plant (engines, pumps, accumulator, &c.), to generate the motive force. This plant, besides its cost, is often difficult to find room for; and if located in some corner of a large shop, the distance to which the pipes have to be carried is a serious drawback. In such pipes frost is often a danger, where they cannot readily be buried, and the fact that the need for such tools is often occasional only makes another difficulty. These objections are obviated by using the ordinary injector to supply the motive power. An injector in good working order will raise water to a pressure about 50 per cent. higher than the steam pressure by which it works. It is therefore only a question of the most convenient method of application. It may be sufficient in many cases to use the actual injector of a locomotive, connecting its outlet direct to the pressure cylinder; but since this connection takes time, it is better to have a portable injector fixed to a small water tank. This injector is connected by flexible tubing to the pressure cylinder at one end, and to the locomotive boiler at the other; the attachment to the latter being made at the opening of the overflow pipe of its own injector. The steam valve of the engine injector is then opened, and the delivery valve closed; the steam is therefore obliged to pass through the opening of the overflow pipe to the portable injector, and thence to the pressure cylinder. Using this arrangement, with a steam pressure of 150 lbs., and with a pressure cylinder of 0·7 mètre diameter (27½ inches) one man can with ease lift and turn on a turntable a locomotive of 35 tons weight, using its own steam for the purpose. The water is at once let off, when required, by opening a cock. The method may also be applied for tipping coal-wagons on wharves; the engine which shifts the wagons supplies the steam in this case, the making and breaking of the connection being so easy that no time is lost. Another arrangement consists of a portable pressure cylinder slung from an elevated beam, and is used for lifting wheels and axles out of a sunken road, which has been done by this means in one-ninth of the time it formerly occupied. Yet another is a portable cylinder of 420 millimètres, diameter (16½ inches), taking the place of a hydraulic jack in cases of derailment, &c. In all these cases the principle is the same, viz., to use the steam of the nearest available boiler (especially a locomotive) to generate the required pressure by means of an injector just as it is wanted, instead of fixed pumps and accumulators to maintain the pressure continuously.

W. R. B.

Experiments with Jordan's Hand-Boring Machine

By G. Szellemy.

(Oesterreichische Zeitschrift für Berg und Hüttenwesen, vol. xxviii., p. 6.)

The Author records the results of experiments carried on with Jordan's hand-power machine at Nagybánya in Hungary, for a

period of three months, driving in greenstone trachyte, and upon a quartz vein. It was not found powerful enough for the latter purpose, but in the former, forty-six boreholes of a total length of 2,720 centimetres (89·4 feet) were bored in eighty-seven hours thirty-four minutes, inclusive of ten hours fifty-eight minutes lost in shifting borers, six hours forty-three minutes in moving the machine from place to place, and twenty-two hours twelve minutes stoppages from the borer jamming in the hole, giving a total loss of thirty-nine hours thirteen minutes as compared with forty-eight hours twenty-one minutes actual working time, or for a single hole of the average depth of 59 centimetres (23·2 inches). one hour and fifty-four minutes, of which sixty-three minutes represent working and fifty-one minutes lost time.

These figures are considerably less favourable than those obtained with ordinary hand work. The speed, so far as actual boring is concerned, being scarcely one-half; and as regards the actual progress of the level, not quite one quarter of the former cost, apart from that of repairing of the machine, being three times as high. This unfavourable result the Author attributes partly to the principle and partly to defects in construction, such as want of stability in the fixing of the machine to the stand, whereby the cam at every revolution tends to shift it from its position; want of power in the blow, so that on meeting a hard vein the borer is unable to cut through, and from its elasticity deviates into the adjoining soft ground; and too great a length of stroke, causing the borer to jam when the hole is not perfectly centred. The use of air compressed at every stroke for giving the blow is considered to cause a loss of 60 per cent. of the power expended, in which particular, however, the machine compares favourably with those driven by power where only 15 per cent. duty is realised. The Author considers that it might be usefully modified by adapting it for water power at very high pressure.

H. B.

Experiments with New Explosives in Coal Mining.

By J. Mayer.

(Oesterreichische Zeitschrift für Berg und Hüttenwesen, vol. xxviii., p. 17.)

The preparations used in the experiments made in the collieries belonging to the Ferdinand's Nordbahn, at Pölnisch-Ostrau, were as follow:—

1. *Peralite*, a coarse-grained powder, made by Procháska and Lisch, at Buda Pest, costing about 60*s*. per cwt., said to consist of potash nitre, 64 per cent., charcoal, 30 per cent., and sulphide of antimony, 6 per cent.

2. *Janite*, made by H. Jahn, at Peggau, a grey coarse-grained

powder, containing potash nitre, 65 to 75 per cent.; sulphur, 10 per cent.; lignite, 10 to 15 per cent.; picrate of soda, 3 to 8 per cent., and chlorate of potash, 2 per cent. This is less inflammable and less violent in its action than peralite, producing a larger proportion of round coal. The cost is 59*s.* per cwt.

3. *Carbazotine*, the invention of Cahuc and de Soulages of Toulouse, made at Dombrau, in Moravia, costing 58*s.* per cwt. It contains 61·04 per cent. potash nitre, 0·73 per cent. sulphate of iron, 24·65 per cent. soot and tan, and 13·58 per cent. sulphur. It is not granulated, is from 60 to 70 per cent. lighter than gunpowder, and tolerably hygroscopic, but may be dried without danger at a stove heat. Being very difficult of inflammation and quiet in action, it is exceedingly safe in use, but must be closely tamped, which can, however, be done with an iron bar.

4. *Carbon Dynamite No. III.*, from Mahler and Eschenbacher, of Vienna, a substance analogous to the weaker kinds of dynamite made by Nobel, containing a certain proportion of nitro-glycerine absorbed by a material which is essentially an imperfect gunpowder.

The trials were made in a seam about 13 feet thick, in headings 6 feet 6 inches square, the explosive being changed at every 10 feet, driven so as to ensure as much as possible uniformity in the conditions of the experiments.

The proportional yield was—

	Large Coal.	Nuts.	Slack.
	Per cent.	Per cent.	Per cent.
With Dynamite No. III. . . .	21·4	35·6	43·0
„ Carbazotine	26·3	37·7	36·0
„ Peralite	19·9	37·7	44·4
„ Janite	22·9	38·5	38·6

The relative efficiency of the different materials being as regards—

	Cost per Ton of Coal of Explosives used.	Value per Ton of Coal got.	
	d.	s.	d.
Carbazotine	2 1/7	10	8 1/4
Janite	2 3/8	10	7
Dynamite No. III.	2 1/20	10	4 1/2
Peralite	2 1/4	10	3

The difference between the highest and lowest of these figures corresponds on the total output of the pits (about 160,000 tons per annum, one half of which is sufficiently hard to require blasting) to about £2,000, saved in the cost of explosives, and increased value of the coal produced.

H. B.

Outburst of Firedamp in a Colliery at Frameries.
By MM. Mallard and Vicaire.

(Annales des Mines, 7th series, vol. xv., p. 575.)

The writers, officially appointed to inquire into the circumstances attending the terrible and singular explosion at the Agrappe colliery, near Frameries, on the 17th of April, were unfortunately prevented from visiting the 656-yards level when the blow of gas occurred, as the mine was still drowned out at that depth. The result of their inquiries from those on the spot, and the conclusion deduced from the information obtained, are, however, embodied in the following.

The three pits, serving respectively for winding, pumping, and for a ladder-way, were, together with the heapstead, covered in. At a depth of 656 yards a level cut the Lévêque and Epinsoire seams; and at the 568- and 601-yards levels are the Grande Sereuse and the Cinque Paulmes seams. At 7.45 A.M. of the 17th a violent current of air issued from the downcast (winding) pit, accompanied with dust and small fragments of coal; a few seconds afterwards the gas ignited at a surface fire, and immediately the whole interior of the building covering the pit was filled with flame, which extended to a height of over 162 feet. The ventilator having been stopped, ineffectual endeavours were made to extinguish the fire. Gradually, however, the flame issuing from the pit lowered, until at 9.45—or two and a quarter hours after the commencement—it was only 6 feet 6 inches above the orifice of the shaft. After flickering for a moment, an explosion took place in the shaft. For twenty-five minutes everything appeared quiet, when another explosion occurred, followed by four others separated by ten minutes' interval. It is believed, from the evidence of the survivors, that all the before-mentioned explosions occurred only in the shaft, but an hour after the last of these a violent explosion took place, extending throughout the mine; and to this must be attributed the fatal and disastrous results.

It can readily be gathered from the foregoing statement, that a blow of gas had taken place of so violent a character as to fill the mine with a mixture containing too little air to be capable of explosion or even of combustion, and thus it was not until the mixture arrived at the surface, and came in contact with the air and with the engine fire, that a flame was produced, and this condition of things continued so long (2¼ hours) as the supply of gas was large enough in relation to the air (which, under the circumstances, commenced to descend by the other pits,) to prevent the mixture from attaining explosive proportions.

It is much to be regretted that the pits were covered in at Frameries, and thus terminated in a building in flames; but for this the colliers could have escaped by the ladder shaft; as it was, a part of the workmen remained at the bottom of this shaft, and

were saved; but, confused by the smoke and reversal of current, the others sought safety in returning to the winding pit, and were overwhelmed in the final explosion. It has been estimated that during the two and a quarter hours preceding any actual explosion, not less than 345,000 cubic mètres (12,184,020 cubic feet) of gas issued from workings, and the total quantity is set down at 500,000 cubic mètres. Not only the Agrappe colliery, but the immediate district, is extremely fiery, so much so that on cutting a seam, or at certain points in working the seams, firedamp is emitted in such quantities as to extinguish the Mueseler lamps, and it is customary to "drain" the coal by putting in advance boreholes. It has been proved by experiments that the pressure of gas in such holes has amounted to 16 atmospheres, although the average is from 2 to 5 atmospheres. Notwithstanding this state of things, powder is used; and a previous accident was undoubtedly owing to the firing of a shot. A short time before the explosion on April 17th, a shot was fired in the drift that was being made to cut the Epinsoire seam, and the gas ignited; but after an interval of ten days, work was resumed, and the coal met with. A short face was opened off, and at the time of the explosion, no communication having been made with the upper level, ventilation was effected by means of air pipes. Boreholes had been put in advance for a distance of 6 mètres, and it was stated that little gas was found to issue from such holes. Amongst other accidents, one in 1874 was caused by an outbreak of gas at a point where the seam was distorted; in this case not less than 196 cubic yards of coal, in a fine state of division, were projected upon and killed five workmen, burying two, and suffocating the three others along the galleries. The gas only fired in the 601-yards level (32 yards above), probably at one of the inset lights, and burnt without explosion. This accident of 1874 was, no doubt, of a similar character to that which occurred on the 17th of April last. Although the same distortion from which the gas came in 1874 extends to lower levels, it is improbable that it will be found at the site of the last explosion; nevertheless, from statistics relating to sudden outbursts of gas in the Belgian collieries, it would appear that when these "blowers" occur it is always at a point where the seam has been dislocated, and generally where the horizontal or inclined seam is bent over. Such blows of gas as these have long been known in Belgian mines, and are made the subject of a memoir by M. de Vaux in the ninth volume of the "Revue Universelle des Mines."

Referring to an explosion at the Midi de Dour Colliery, in 1865, M. de Vaux makes the following remarks, which apply directly to the circumstances attending the Frameries explosion:—"Should a sudden outburst of gas take place near the downcast, part of the gas, proportionate to the ventilating power, will course through the mine; the surplus, which may be considerable, will lodge in the downcast pit, and by its levity may ascend so as either to retard or actually to reverse the current. At the surface, or in

passing lights at higher insets, the gas may be ignited, drawing together gas and surrounding air. The latter soon attains the sufficient proportion for a violent explosion; but the flame at the pit mouth is unextinguished until the quantity of air assumes such proportion that a final explosion takes place in the pit itself."

The incidents of such outbursts are always similar, viz., a dull sound, or alternately a violent report, the rolling down of the face, and the projection of a vast quantity of coal dust (fusain). The advance borings generally give off but little gas for some days before an outburst. In some cases a cavity, more or less extensive, is found; but it appears incomprehensible that a cavity exists in the coal measures which would give off the enormous quantity of 500,000 cubic mètres of gas within a few hours, even if such gas were in a state of compression. Hitherto it has not been found that cavities exist proportionate to the quantity of gas given off and the quantity of dust simultaneously projected. At the same time it must be remarked, in conjunction with the fact of the outbursts occurring at the curving over of a seam, that a break may extend to a great length, although it may have but a small transverse section.

The theory that the gas may exist in a liquid state certainly obviates the apparent necessity of a large cavity, and likewise would explain the curious fact of advance boreholes giving off little gas prior to an outburst, but at the same time it is difficult to account for the provision of the large amount of heat necessary to instantaneously convert the liquid into gas. The outbursts being always accompanied with a great quantity of fine dust, renders it necessary that an explanation of such fact be included in any sound theory.

The outbursts of gas, so far as the statistics of Belgian cases are concerned, do not occur at much less depth than 392 yards. Out of eleven cases, nine took place at depths varying from 415 to 614 yards, and two only at 380 and 402 yards.

Some remarks are made as to the impracticability of dealing with such outbursts by any amount of ventilation, and some precautions as to naked lights at the surface, &c., are given.

A. S.

Machine for Washing and Sorting Coal.

By Max Evrard.

(Revue Industrielle, 1880, p. 105.)

This machine is employed for the double purpose of washing the finer portions of the raw coal charged into it, and at the same time of sorting the entire charge according to the size and relative densities of its constituent bits. These are sorted ordinarily by the machine into three layers, of which the uppermost comprises

the slimes and the smallest sizes of coal sufficiently cleaned; the middle layer is stuff to be washed over again; while the bottom is refuse shale. The apparatus consists of a deep kieve or open tank,[1] in which works a loosely fitting table or sieve, raised and lowered by a hydraulic cylinder beneath. While the table is down, water is admitted into the bottom of the kieve from a large closed reservoir under steam pressure; and as soon as it rises about 3 feet above the table, the charge of stuff is dropped into it from the top of the kieve; after which the steam pressure is made to act intermittently in the reservoir, so as to deliver the further supply of water into the kieve with a series of jerks, whereby the charge is held in suspension in the water until the water reaches the top of the kieve. The admission of water is then stopped; and the stuff, after having thus encountered a succession of checks to its descent, now falls freely through the still water, and settles down upon the table. After a few minutes' rest, the table is raised; the water above flows off at the top of the kieve; and the charge as it emerges is struck off in successive layers by means of a scraper worked horizontally by a hydraulic cylinder. The pressure water for working the two hydraulic cylinders is supplied from a closed vessel under full steam pressure; and the exhaust steam from this smaller vessel is afterwards expanded into the larger closed reservoir that supplies water to the kieve. The consumption of steam is 0·6 per cent. of the weight of stuff washed, or about 13½ lbs. per ton of stuff. About 7 tons of stuff can be treated in ten hours per square foot of table area; very large charges can thus be worked in a machine of moderate size. Owing to the great range of lift allowed to the table, the machine serves equally either for washing in the foregoing manner by an upward jerky current of water, or for washing in still water by filling the kieve full of water to the top beforehand: either dropping the charge to the bottom, in the case of stuff too fine to separate easily without falling into the water from some height; or else delivering it into the water at the top of the kieve without drop, in the case of riddled slack so tender as to break with any fall.

By this machine badly riddled stuff is sorted according to size and density in a manner that is good enough for many commercial purposes. Thus at the Roche-la-Molière and Firminy company's collieries (in the department of the Loire, France) coke containing not more than 12 to 14 per cent. of ash is readily obtained by this means, without loss in slimes and without washing any portion of the charge a second time over, from raw coal containing 17 per cent. of ash; while by re-washing in a piston jigger the whole of the middle layer in each charge from the Evrard washer, the percentage of ash in the coke is reduced from 14 to only 8 per cent. The jigger employed for the re-washing at Roche-la-Molière is a

[1] See also "Bulletin de la Société d'Encouragement pour l'Industrie nationale," 1875, p. 30.

horizontal annular table or grid of 13 feet outside diameter and 86 square feet area, with central jigging piston; it has a slow rotation of one turn in three minutes, and the stuff to be re-washed is fed upon it in a layer of about 3 inches thickness, being at the rate of about 10 tons per hour. With the attendance of only two men, from 200 to 300 tons of riddled slack are treated per day in the washer and re-washer at the above works. M. Evrard's machines are also in operation at Montcel-Sorbiers colliery (Loire); at Givors coke works in the same district; and at Barruelo colliery in Spain, belonging to the Northern Railway of Spain.

A. B.

Comparison between the Average Costs of Production of Iron in France and in England. By M. Danelle-Bernardin.

(Revue Industrielle, 1880, p. 9.)

In the course of a Report drawn up on behalf of the Commission of the Chamber of Deputies appointed to consider the suitability of the rate of duty of 6 francs per 100 kilogrammes proposed to be charged on malleable iron imported into France, the Author discusses at some length the relative costs of production of bar iron in France and in England.

He estimates that English coal costs, on the average, 6·25 francs per ton at the pit's mouth, and French coal 11 francs; and that, at the same time, French coal of average quality is so much inferior for smelting purposes to English coal, that 1,600 kilogrammes of it are needed, as compared with 1,350 kilogrammes of English coal, to make a ton of coke; and the coke contains 12 to 16 per cent. of ash, against 6 per cent. only in England, so that 1,200 kilogrammes of it, instead of 1,100 kilogrammes only, are required in the blast furnace per ton of pig iron made. In the cost of the coke only, that is used in the blast furnace, the expense of making pig iron in France thus exceeds that of making it in England by more than 12 francs a ton.

France, it is estimated, is at a further disadvantage in the cost of carriage of the iron-making materials to each other or to the works. This is owing in part to the fact that iron ore and coal lie much further apart in France than in England, and in part to the want in the former country of a more complete system of canals, so that the materials have to be conveyed, to a great extent, more expensively by rail.

It is assumed that the cost of the labour required in iron-making is the same in both countries, and that the cost of the ore at the mine, and its average richness, and the cost of fluxes, are also the same; but the Author remarks, that in the richness of its ores, and in the proportion of lime that must be smelted with them, for fluxing, on account of their siliceous character, France is also

in truth at a disadvantage as compared with the competing countries.

The following is a summary of the relative costs of production of cast and wrought iron in the two countries, noting only the items of expense in respect to which they differ. In France, the works that produce pig iron convert it also, habitually, into wrought iron. In England, on the contrary, the pig iron is more commonly carried to a point nearer to the collieries, to be there made into wrought iron. Hence, in this estimate, the carriage of the coal used is charged as part of the cost of making pig iron into wrought iron in France, and the carriage of the pig iron as part of the cost in England—

1. Production of pig iron :—

France.	Francs.	England.	Francs.
Coke, 1,200 kilogrammes at 20·60 francs	24·72	Coke, 1,100 kilogrammes at 11·45 francs	12·60
Carriage of this coke, at 8 francs	9·60	Carriage of this coke, at 4 francs	4·40
Carriage of 3 tons of ore, at 3·50 francs	10·50	Carriage of 3 tons of ore, at 1 franc	3·00
Total of these items	44·82	Total of these items	20·00

Difference in favour of England, 24·82 francs per ton.

2. Conversion of pig iron into wrought iron :—

France.	Francs.	England.	Francs.
Pig iron, 1,400 kilogrammes at 44·82 francs	62·73	Pig iron, 1,400 kilogrammes at 20 francs	28·00
Coal, 2,500 kilogrammes at 11 francs	27·50	Coal, 2,500 kilogrammes at 6·25 francs	15·63
Carriage of this coal, at 8 francs	20·00	Carriage of the 1,400 kilos. of pig iron, at 4 francs	5·60
Total of these items	110·23	Total of these items	49·23

Difference in favour of England, 61 francs per ton.

Germany and Belgium are at a greater advantage than England in their cost of producing iron; as though their coal is no better than French coal, labour with them is 30 per cent. cheaper. Thus the average cost of coal in Belgium being 8 francs per ton, and in Germany 6 francs per ton, the difference in the cost of production of bar iron, as compared with that in France, is estimated to be 63·10 francs per ton in favour of Belgium, and 73·48 francs per ton in favour of Germany.

France is at even a greater disadvantage as compared with foreign countries in the production of high class charcoal iron than in that of coke iron, and the make of this class of iron in the

country has fallen off from 90,654,000 kilogrammes in 1859 to 21,100,000 kilogrammes in 1877, a quantity only equal to that imported in the same year. The difference between the cost of production of charcoal bar iron in France and in Sweden is not less than 120 francs per ton.

W. H.

Experiments on Generator Furnaces Burning Coke, under various Conditions of Draught.[1]

Made by a Commission of the Verein von Gas- und Wasserfachmännern Deutschlands.

(Journal für Gasbeleuchtung und Wasserversorgung, vol. xxii., pp. 110 *et seq.*)

The coke used for the third series of experiments was made from Zwickau coal, and was in smaller pieces, and harder, than that used in former trials. The generator furnace was the same as before, its walls having been glazed by the heat. All cracks were carefully luted with fire clay. In the first experiments the results were unsatisfactory, owing to the resistance encountered by the gases in passing through the fine coke. The thickness of the coke layer was diminished, and the draught increased, when the yield improved. At the same time one of the air-slits was closed, and the quantity of gas found to diminish in consequence. The furnace was then filled with coarse-screened coke, which was easily and rapidly converted into gas. During the nine days these experiments lasted, there was no difficulty in removing the cinder, which was fused, and run down to the bottom of the furnace. The effect of a small quantity of steam on the yield of gas was then tried, the bottom of the furnace being fitted with a fire-grate, through which the steam was introduced. The cinder was found to cake upon the bars, so as to render its removal difficult; and an accident to the pump of the boiler which supplied the steam terminated this series.

Numerous analyses were made to determine the influence of the thickness of the coke layer upon the composition of the gas, and samples of gas taken from different heights in the furnace were analysed. It was found that the percentage of carbonic acid increased with the draught. The temperature in the gas passage was not diminished by the use of steam. The amount of heat required to decompose the steam was, therefore, not greater than that usually lost from the furnace through radiation. When sufficient steam was injected through the iron fire-grate, the ashes did not clinker, and could be removed without difficulty. A certain

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[1] Continued from the Minutes of Proceedings Inst. C.E., vol. lv., p. 422.

quantity of steam could be completely decomposed in the furnace, hydrogen being liberated. The weight of steam used to each kilogramme of coke varied from 0·42 kilogramme to 1·62 kilogramme; but the best results were obtained with from 0·7 to 0·8 kilogramme of steam. When the proportion of steam was less, the ashes clinkered and were difficult to remove; when an excess was tried, the temperature of the furnace gradually sank, and steam passed through without being decomposed. The percentage of carbonic acid increased with the amount of steam, showing that the decomposition of aqueous vapour is more easily effected by incandescent carbon, than the reduction of carbonic acid to carbonic oxide. The proportion of combustible gases increased with the steam used, till the latter exceeded 0·82 of the weight of the coke. The calorific effect of the gas upon each unit of coke consumed in the furnace was greater with steam than without.

The coke used for the fourth series of experiments was made from English Newcastle, and Primrose coal.

Eight trials were made with the side apertures for the admission of air, and seven with fire-grate and steam. In general it was found that an increase of draught, corresponding to 1 millimètre pressure, caused an increased consumption of coke, amounting to 200 kilogrammes in twenty-four hours. Both the proportion of carbonic acid in the gases, and their temperature on leaving the furnace, increased with the draught. The slag of the English coke was easily fusible, and was removed without difficulty; but the sides of the furnace, especially near the air-slits, were much corroded. A good heating gas was produced with a layer of coke only 0·5 mètre in thickness; and it appears probable that a large proportion of the carbonic oxide is formed direct from the coke, and not by subsequent reduction of carbonic acid.

The draught employed in the different experiments varied from 1 millimètre to 8·8 millimètres. The slag was removed at different intervals, the effect on the yield of the furnace being noted. The result of about fifty observations showed that the slag or ashes should be removed hourly, in order to produce the most favourable effect. A considerable increase of draught was observed each time the ashes were removed. The seven experiments with fire-grate and steam made it evident that the composition of the ashes or slag is of the greatest importance in working a generator furnace. The steam should be so regulated that the ashes do not clinker; they should lie loosely upon the bars of the fire-grate.

A fifth series of ten experiments was conducted in a similar manner to those already described. The coke used was made from Westphalian coal. The results obtained were analogous to those of the preceding series. The slag of this coke was found to melt as easily as that from English coal, but the walls of the furnace were less corroded. During one of these experiments the loss of heat due to radiation through the air-slits was determined, and found to amount to 8·3 per cent. The quantity of steam which

sufficed in this instance to prevent the ashes from caking was 50 to 60 per cent. of the weight of the coke.

A further series of twelve tests was undertaken with coke made from Silesian coal. As in all the preceeding series, each experiment is described in detail. The proportion of incombustible residue left by this coal was small, being only 7·4 per cent. In two experiments one air-slit only was opened, and the loss of heat by radiation through this aperture varied from 3·2 to 6·1 per cent., according to the draught. With this material the most favourable proportion of steam was 66 to 71 per cent. of the weight of the coke.

It having been found that the degree of fusibility of the ashes had great influence on the working of the furnace, analyses of these ashes were made.

The fire-bricks, especially those in the neighbourhood of the air-slits, were much corroded by the fused cinder, the most compact fire-bricks proving most durable, even when their chemical composition was less favourable.

Taking the average of all experiments, the composition of the gas generated in the furnace with air-slits was:

With a low draught (± 1 millimètre) 1·9 per cent. CO_2; 28, 3 per cent. CO; temperature 500° centigrade.
With a strong draught (7–10 millimètres) 5·8 per cent. CO_2; 22·6 per cent. CO; temperature 1,000° centigrade.
With fire-grate and steam 30·6 per cent. combustible gases, temperature 700° centigrade.

On account of the long gas passage, a loss of heat took place in all these experiments, which might be avoided by placing the combustion chamber nearer the generator.

E. S.

On Gas Separation in Bessemer Ingots. By F. G. C. Müller.

(Zeitschrift des Vereines deutscher Ingenieure, vol. xxiii., p. 493.)

This is the detailed account of the results obtained by the Author's method of boring ingots in water and collecting the gas in the cavity formed by the drill, which formed the subject of a preliminary communication to the German Chemical Society.[1] The volume of gas is given in percentage of the cavity when measured and reduced to atmospheric pressure. An approximate value for the tension of the enclosed gas was arrived at by weighing the ingot before and after boring, the difference of these quantities divided by 7·8 gives the volume of metal removed, the difference between it and the measured volume of the cavity that of the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lvi., p. 360.

enclosed gases, and dividing the measured volume of the gases by the last quantity gives the tension in atmospheres.

The complete series of results obtained are as follow:—

——	Volume of Gas.	Tension, Atmospheres.	Hydrogen.	Nitrogen.	Carbonic Oxide.
	Per cent.		Per cent.	Per cent.	Per cent
I. Bessemer rail steel	48·0	..	90·3	9·7	..
II. " spring steel	21·0	..	81·9	18·1	..
III. " metal before adding spiegel	60·0	3·5	88·8	10·5	0·7
IV. " " finished from preceding . . .	45·0	7·0	77·0	23·0	..
V. " pig metal from cupola .	15·0	..	86·5	9·2	4·3
VI. " " another sample	35·0	..	83·3	14·2	2·5
VII. Pig metal, Solway No. I. . . .	3·5	..	52·1	44·0	3·9
VIII. Martin metal, Bochum, before addition of spiegel	25·0	..	67·0	30·8	2·2
IX. Bessemer rail steel	29·0	8·0	76·7	26·3	..
X. Pig iron from converter, during blowing of IX.	28·0	..	81·1	14·8	4·1
XI. George Marien Hütte No. 1 pig .	10·0	..	62·2	35·5	2·8
XII. Westphalian mild Bessemer metal .	16·5	..	68·8	30·5	..
XIII. Rail steel from Prevali	51·0	4·5	78·1	20·7	0·9
XIV. Unsound rail steel forged . . .	5·0	..	52·2	48·1	..
XV. Very spongy rail ingot metal, rolled	7·3	..	54·9	45·5	..
XVI. Bochum compact steel ingot . .	17·0	..	92·4	5·9	1·4
XVII. The same forged	5·5	..	73·4	25·3	1·3

From these analyses the Author concludes that unsoundness in Bessemer ingots is to be attributed, not to carbonic oxide, but to hydrogen, resulting from the decomposition of water vapour contained in the air[1] of the blast, which is absorbed by the molten metal and more or less completely given off in cooling. The effect of carbonic oxide, whether developed by combustion in the charge during the blowing or on the addition of spiegeleisen, he considers to be mainly mechanical, and beneficial in so far as it removes the dissolved hydrogen in the same way that air blown through ammonia, iodine- or bromine-water, for a sufficient length of time, removes these dissolved volatile substances. The good effect of spiegel is therefore most efficiently realised when the metal is fully overblown—a condition which is however only possible when the metal treated is comparatively free from manganese; and as a consequence the Author considers that the deoxidation of such overblown metal should be effected with pig-iron poor in manganese, and the recarburisation and final addition of manganese by spiegel or ferro-manganese. Whether a metal will cast sound

[1] This is borne out by the analyses of the gases given off in the converter, which contain 2·5 and 2·8 per cent. of hydrogen respectively.

or spongy depends upon the facility afforded for absorption of nitrogen and hydrogen while in the fluid state, and this, in the Author's opinion, so far as cast steel is concerned, depends mainly upon the texture of the crucibles; if these are porous the furnace gases will have easy access to the interior, and the effect will be most marked with hydrogen from its rapid diffusibility.

H. B.

Gas Furnace for Burning Bricks, at Perm. By — Radloff, M.E.

(Gorny Journal, vol. iv., p. 338.)

There has recently been set to work at the Imperial Cannon Foundry at Perm a continuous-action furnace for burning bricks of quartz, fire-clay, and other refractory material, the heat for which is derived from the generator supplying gas to all the ovens in the factory. It consists principally of an arched tunnel, 54 feet (Russian) long, 6 feet wide, and 7½ feet high, the furnaces being disposed at the centre of its length, six on each side. The floor of the tunnel is furnished with rails, on which run eight wagons carrying the charge, and each end is closed by an iron door. In working, one wagon is run into the tunnel at every shift in a direction contrary to the draught of the furnace, and remains at the tail of a line of eight similar wagons till the succeeding shift advances it a stage. In this way the materials are gradually prepared for the intense heat of the furnace flame, and after burning are as gradually cooled. At present only one charge is introduced every twelve hours, but that rate could be exceeded if necessary. Only three workmen are required to regulate the gas, load the wagons, and run them in.

E. A. B. H.

On the Action of Coke Slag on Fireproof Materials.
By Dr. B. Kosmann.

(Journal für Gasbeleuchtung, vol. xxii., p. 583.)

These experiments were undertaken with the object of ascertaining what relation exists between the composition of the fused slag resulting from the combustion of coke at a high temperature and the deterioration of the fire-bricks subjected to the action of such slag. At the same time, and for the purpose of comparison, analyses were made of the ash produced by the same coke when burned at a lower temperature. It has been usual, in investigating the action of the slag produced by fuel upon fireproof materials, to analyse the ash of the fuel before it has undergone

fusion. That such a practice must, in many cases, lead to erroneous conclusions may be seen from the examples given below. The experiments were conducted in regenerator furnaces for heating gas retorts. In these furnaces the fire-bricks, especially in the neighbourhood of the slits through which air is admitted, are very rapidly corroded, unless their composition is adapted to the acid or basic nature of the slag with which they are brought into contact.

The first series of experiments was made with a regenerator furnace on Müller and Eichelbrenner's system. The coke used was from the Gelsenkirch district, and contained 11·92 per cent. of ash. When produced at a temperature which did not suffice to fuse it, the composition of this ash was that given under A. B is the ash of the same coke fused at the temperature prevailing in the furnace.

	A.	B.
Silica	47·91	62·95
Alumina	30·17	25·23
Ferric oxide	12·16	..
Ferrous "	..	3·12
Manganic "	0·38	..
Manganous "	..	0·28
Lime	1·41	0·46
Magnesia	1·22	0·92
Soda	2·60	2·82
Potash	3·34	3·51
Sulphuric acid	0·82	..
Phosphoric "	..	0·55
Metallic iron	..	0·09
Ferrous sulphide	..	0·04
	100·01	99·97

The fused slag formed a dark glass of the specific gravity 2·52, and enclosing globules of metallic iron. At the higher temperature, therefore, both iron and manganese had been reduced to lower stages of oxidation, part of the former even to the metallic state. The sulphates of lime and magnesia had been either volatilised or removed by mechanical means, and the potash and soda remained in the slag. Although the ash is of a decidedly basic character before fusion, yet the slag produced from it is acid. In this case the use of fire-bricks with an excess of acid constituents was indicated. Those used contained 89 per cent. of silica, and resisted the action of the fused slag remarkably well.

In the second series of experiments the regenerator furnace was constructed on Liegel's system. The coke was made from a mixture of ⅔ Nettlesworth and ⅓ Leverson coal. The proportion of ash in the coke was 9·24 per cent.; its analysis is given in the following Table under A. After the furnace had been working for three days the sample B was taken. It was but partially fused, the action of the furnace being imperfect, owing to the

air-slit being too large. When this had been reduced in size the slag was easily fused, and had the composition C.

	A.	B.	C.
Silica	43·34	{51·80}	34·55
Titanic acid	0·86		3·40
Alumina	21·16	29·27	41·26
Ferric oxide	11·84	11·24	..
Ferrous "	..	..	0·43
Manganic "	0·61	1·26	..
Manganous "	..	..	0·25
Lime	10·53	6·85	15·14
Magnesia	0·41	1·12	0·57
Soda	0·86	0·33	0·06
Potash	1·88	0·70	0·67
Sulphuric acid	7·17	..	..
Phosphoric "	0·61	..	..
Sulphur	..	..	0·19
Metallic iron	..	..	3·75
	99·27	102·57	100·27

The apparent excess in B is due to the oxygen of the iron and manganese compounds, part of which were present in the lower stage of oxidation. The presence of titanic acid is remarkable in these analyses. The changes which took place during the first stage of fusion (B) were not important. In the second stage (C), when completely fused, the slag became more basic in its character than the ash from which it was derived. There was a considerable reduction of metallic iron, which was found in numerous globules nterspersed throughout the dark, vitreous mass. In this case also the sulphates had been volatilised. The iron globules were very impure, containing only 36 per cent. of metallic iron.

After the furnace had been in work some months the draught became defective, and, on the flues being opened, they were found lined with a ¾ inch coating of a light, porous substance, which was found on analysis to contain 72 per cent. of silica and a large proportion of sulphates. It probably owed its origin to the decomposition of the slag by steam, assisted by the action of the sulphates present. This furnace was lined with fire-bricks containing as high a proportion of alumina as possible; they resisted the action of the basic slag so well that their wear was almost imperceptible.

The coal used in the third series of experiments was from Upper Silesia, and contained 3·54 per cent. of ash, of the composition given below under A.

	A.	B.
Silica	61·18	61·32
Alumina	26·07	23·79
Ferric oxide	7·32	..
Ferrous "	..	7·41
Manganous "	..	0·78
Lime	1·32	3·60
Magnesia	1·18	1·50
Soda	0·33	0·80
Potash	1·79	1·35
Loss as gas	0·47	..
	99·66	100·55

The regenerator was lined with the best Garnkirk fire-bricks; but, as will be seen from the analysis B, the slag was of so acid a nature that these bricks were speedily corroded, and in a short time completely destroyed. Other bricks, containing 89 per cent. of silica, were therefore substituted, and left nothing to be desired with regard to durability.

W. F. R.

Electrical Storage. By E. J. Houston and E. Thomson.

(Journal of the Franklin Institute, vol. cviii., p. 388.)

The various suggestions hitherto made for the storage of electrical energy, have chiefly failed by reason of the extent of conducting surface required, the loss of energy when charging, want of constancy and duration in the derived currents and the limited capacity for storage; Planté's secondary battery has all these inconveniences.

In the system of electrical storage devised by the Authors, the duration of action and capacity for storage is independent of extent of surface, and dependent on the mass of material to be acted upon. A saturated solution of zinc sulphate is employed, enclosed in a suitable vessel, at the bottom of which is placed a plate of copper, connected to an insulated conducting wire. Immersed in the solution, and arranged near the top of the vessel, is a second copper plate, also connected to a wire. A charge of this storage cell is effected by the passage of a current from a dynamo-electric machine, whose direction is from the lower to the upper plate; this results in the deposition of metallic zinc on the upper plate, and the formation of a dense solution of a copper sulphate overlying the under plate. The duration of the charging action is limited by the amount of zinc sulphate and the thickness of the lower plate, the cell after charging constituting a gravity cell, and continuing a source of electrical current, until a reconversion of the copper sulphate into zinc sulphate has been effected, metallic copper being deposited on the lower plate and the zinc removed from the upper. When this takes place it is in its original condition. The recharging may be effected at any time, either before or after the cell has become inactive. The cell may be sealed to prevent evaporation, and since no addition of new material is needed, it may at any time be restored to an active condition. Suggestions are given as to the arrangement of such cells in series, and mention made of the numerous applications for a storage battery. The Authors, in conclusion, state that it is practicable, in good forms of dynamo-electric machines, to realise, for external work, from 50 to 60 per cent. of the power utilised to drive them, and that it is possible to store and recover 50 per cent.,

or even more; therefore 25 per cent. of the original power may be given out secondarily as electric current. If in the best steam engines it is possible that 20 per cent. of the heat energy of the coal can be utilised, then about 5 per cent. of the heat energy might be recovered, after storage as electric current.

E. S.

On a Simple Method of using an Insignificant Fraction of the Main Current, produced by a Dynamo-Electric Machine for Telegraph Purposes. By L. Schwendler, M. Inst. C.E.

(Proceedings of the Asiatic Society of Bengal, 1879, p. 256.)

The Author points out that, up to the present, the electric currents required for telegraph signalling are chiefly produced by galvanic batteries—a method comparatively expensive, and also connected with cumbersome arrangements. Since his electric-light experiments, instituted last year in London by order of the Secretary of State for India, he had always been of opinion that it would be of technical, as well as of economical importance if the strong, constant, and exceedingly cheap currents produced by the present construction of dynamo-electric machines could be made available for signalling purposes. However, it was found at the time that there were some difficulties in the way, which it is believed have now been overcome. The Author's method was to produce a strong current through a comparatively small resistance by a dynamo-electric machine. The current so produced is available for any kind of useful work; such as giving out a powerful electric light at night, or driving an electro-magnetic engine by day, which in turn is used for doing any kind of useful mechanical work, as pulling the punkahs, producing a draught of cool air through the building, lifting, messages, &c. Or, the main current may be sent through a large galvano-plastic apparatus in use, say at the Surveyor-General's office. Thus a strong electric current becomes available, the production of which is wholly or partly repaid by the useful work it is able to execute.

On the other hand, the currents required for signalling purposes are exceedingly weak as compared with the strong main current. Hence the electric currents may be supplied to the telegraph lines by simply tapping the main current, without perceptibly reducing it, or without influencing the useful work it effects. In this way telegraph administrations might introduce electric light in their offices, and get the signalling currents for all lines terminating in an office into the bargain, thus dispensing with the costly and cumbersome galvanic apparatus. On the 14th October, 1879, Mr. Schwendler telegraphed by this method to Agra. The main current was produced at the Alipore Government telegraph workshops, and the useful work consisted of a powerful electric light illuminating

the workshops perfectly. An ordinary telegraph line conveyed the branch current to the Calcutta signalling office, where it was joined to the Agra line (850 miles in length), and several messages were dispatched by the use of this current. No alteration of the electric light could be observed when telegraphing. The signalling current drawn off was scarcely 0·04 per cent. of that producing the light. Other experiments equally successful were made, and, in fact, feeding in this manner all the fourteen lines terminating at the Calcutta office scarcely required more than 5 per cent. of the total main current. The Author was of opinion that, in the near future, telegraph lines would be supplied by currents produced by dynamo-electric machines, instead of using galvanic currents as hitherto.

Gramme's Improved Dynamo-Electric Machine. By H. Fontaine.

(Revue Industrielle, 1880, p. 53.)

The Author here describes a new arrangement of dynamo-electric machine, by M. Gramme, the improvement embodied in which consists in the combination of the small machine, hitherto used as an exciter, with the large machine or distributor, through which the small continuous machine passed a current. For this purpose the general design of the two earlier machines is entirely altered. On a cast bed plate are fixed two circular side-frame cheeks carrying the main bearings at their centre and being held apart by six square iron bolts. On the inside of one of the frame cheeks is a deep flange forming a short cylinder. Inside this, as four radii, are fixed the exciting electro-magnets, within the inner ends of which runs the small exciting coil fixed on one end of the shaft, the other part of which carries six large revolving electro-magnets attached to a sleeve fixed on the shaft. The alternating current coil rests on the square bolts connecting the frame cheeks with interposed hard-wood packing pieces. The six large electro-magnets thus revolve within a large circle formed by the six adjoining alternating current coils. The coils of the revolving electro-magnets communicate with the exciting circuit through a wire brush. Two wires are wound in making the coil instead of one, and thus tension currents are obtained for small lights, and quantity currents for large lights. Experiments are quoted which show that a greater quantity of electricity and a steadier light are obtained by this combined machine than with the separate machines. A machine arranged for small lights and driven at twelve hundred and fifty revolutions per minute, gave fourteen lights of 20 Carcel-burner power, with an expenditure of 350 kilogrammetres per second or 4·6 HP.

W. W. B.

On the Current from the Gramme Dynamo-Electric Machine.

By O. E. MEYER and F. AUERBACH.

(Annalen der Physik und Chemie, new series, vol. viii., p. 494.)

The Authors have, from a long series of experiments, determined the relation existing in the dynamo-electric machine of the type under consideration between the velocity of rotation of the armature and the current thereby generated.

If the curves are plotted out from the data given below it will be seen when the external resistance in circuit is equal to the internal resistance of the machine, that when the machine makes more than 300 revolutions per minute the curve is nearly a straight line, or the intensity of the current is at first proportional to the velocity of rotation.

The internal resistance of the machine was 1·02 S.U.

Velocity of Rotation.	Intensity of Current in Webers, with Total Resistance in Circuit of—			
Revolutions per Minute.	1·75 S.U.	2·00 S.U.	2·50 S.U.	3·00 S.U.
20	0·05	0·04	0·03	0·03
40	0·11	0·09	0·07	0·06
70	0·21	0·17	0·13	0·11
100	0·36	0·27	0·21	0·18
150	0·77	0·50	0·33	0·26
200	2·29	1·85	1·15	1·00
250	6·10	4·81	2·96	2·30
300	10·35	8·73	5·87	3·77
400	17·48	14·74	10·86	7·54
500	23·33	19·25	16·61	12·50
600	28·51	23·05	20·30	16·40
700	31·90	26·63	22·79	19·12
800	35·80	30·72	25·43	21·55

These experiments show the anomalous result of the highest E.M.F. reached at 3 units in circuit; whereas the E.M.F., being a function of the intensity of the current, it should increase with decrease of total resistance in circuit. This would seem to show some fault in the machine used, appearing when the current reached a certain intensity. The values of the E.M.F. in volts, calculated from the above Table, are—

57·01	58·55	60·58	61·64

F. J.

Influence of the Nature of the Carbons used for the Electric Light. By Count Du Moncel.

(Comptes rendus de l'Académie des Sciences, vol. xc., p. 64.)

Referring to Edison's recent announcements as regards the solution of the problem of electric lighting, the Author quotes his own published experiments as far back as the year 1855, which proved the superiority of carbons of vegetable origin over those of animal or mineral in increasing the brilliancy of the electric light; such vegetable carbon being therefore used for the Author's small electric lights for clinical purposes, though, on account of the heat evolved, preference was given to Geissler tubes. In the lamp of Dumas and Benoît the luminous part was actually shaped as a horse-shoe, but was altered into a spiral at one end to increase the luminous effect. Carbons of vegetable origin could be used more advantageously only in a vacuum, as otherwise the waste would be far greater than with retort carbon.

F. J.

The Dynamo-Electric Machine and its Application as the Motive Power on an Electric Railway. By Dr. Werner Siemens.

(Electrotechnische Zeitschrift, vol. i., p. 47.)

After giving a short history of the development of the machine, the Author comes to the special subject under consideration, cautiously mentioning that he does not propose that electricity should supersede steam as a motor on all railways; but, as in lighting by electricity or by gas, the two methods will find their own fields. When one dynamo machine is driven by another, the driven will generate a current in the opposite direction to that produced by the driving machine; from which consideration it is evident that the maximum power must be produced at a certain speed for the driven machine, and by the Author's calculation for two *similar perfect* machines, this would be when the driven machine is running at one-third the speed of the other. By a perfect dynamo machine is understood one in which the mass of iron is such, that the magnetic intensity is proportional to the current in the convolutions, and in such, when the current is closed in itself, the work is proportional to the third power of the velocity of rotation. In practice this is not so, due to the increase of the resistance of the brush contacts and the molecular resistance of the iron to magnetisation at the higher velocities. This being the velocity at which the maximum work is produced, does not mean that the efficiency of the machines is only one-third, but the power reproduced in useful work is proportional to the velocities

of the two machines. From numbers of experiments recently made at moderate velocities the useful work was 40 to 50 per cent. of the expended, and at higher velocities as much as 60 per cent. was obtained. It is perhaps merely a question of the size and velocities of the driving and driven machines, whether a still higher percentage of power may not be regained. Now comparing the useful effect obtained from large boilers and stationary condensing or compound engines, and that from the high-pressure locomotive engines, it is possible that the 50 per cent. of the dynamo-electric transmission may be as economical, seeing that there is little loss in originally producing the electricity. One advantage could certainly be obtained from the use of electricity on railways, as by its means a greater adhesion of the wheels on the rails could be effected, so that steeper inclines would be allowable, and tunnels consequently shortened or altogether omitted; and, on the other hand, resulting in a more powerful means of securing efficient brakes. Thus it would be desirable for mountain railroads, and those used for construction or mining operations. Other appropriate applications would be for small railways for transmission of postal messages, analogous to the pneumatic tube system, but available for longer distances than the latter, and for "elevated railways."

For postal service the Author proposes a small covered railway track about 18 inches high, mounted on short iron columns, erected alongside existing railways, or by any other route, as the gradients could be adjusted by using columns of proportionate heights. Small drawings are inserted of the general plan of the details, the two rails being insulated from each other by being mounted on wooden sleepers, one being in connection with the sheet-iron covering, the other in connection with the earth by means of the iron supporting columns, to form the conductors for the current generated by the stationary machine; the circuit being established with the motor on the axle through the wheels by suitable commutators. The electrical resistance of such a system of conductors would not amount to more than 0·02 Siemens' unit per kilomètre, so that one stationary machine would suffice for a length of 20 kilomètres. If the stationary machine were of such construction as to give a considerably more powerful current than the motors, the speed of a carriage would not be sensibly diminished if others were introduced on the rails at the same time; it being a property of the dynamo machine that the power increases at a greater ratio than the speed of rotation; as the motors could be designed to turn 800 or 1,000 times per minute, a speed of 1 kilomètre per minute with such a railway could easily be obtained. At the present high price of iron the cost of such a line is estimated at 18,000 marks per kilomètre (say £900). For the "elevated railway," by a proper construction of girders and strong supporting columns, which would raise it sufficiently from the roadway to allow the maintenance of the traffic as usual, the resistance per kilomètre be reduced to 0·011 Siemens' unit per kilomètre; so that

a length of line, sufficient for a circular railway in the largest towns, could be worked by one stationary machine. The cost of such a line is estimated at about 150,000 marks per kilomètre (say £7,500), and a speed of 30 to 40 kilomètres per hour could be obtained. Of course any other arrangement of conductors might be applied, as, for instance, a central conducting wire supported between the rails on glass or furnace-slag carriers, which could be lifted by suitable rollers on the carriages, and thus establish electrical communication with the motors; or a central insulated fixed rail could be applied for the same purpose. An actual working line constructed on the last form was shown at the Berlin exhibition, consisting of an electric locomotive drawing three cars, each constructed to carry six passengers; and here it was noticed how slight a variation in speed was caused if the cars were empty or doubly or trebly loaded with their complement of passengers. The Author concludes by hoping that as Berlin was the birthplace of the dynamo-electric machine, in that town also may the first dynamo-electric railway be erected.

F. J.

Lightning Protector for the Telephone.

(Archiv für Post und Telegraphie, 1879, p. 741.)

During the past summer (1879) more than 11 per cent. of the telephones in use on the German Government lines were fused by lightning.

The coils of the telephone are now protected by introducing between them and the line a protector consisting of a hundred turns of fine (0·1 millimètre) silk-covered wire wound on a brass rod about 5 millimètres diameter and 30 millimètres long, this rod being in connection with the earth. Such a simple arrangement can be at once replaced if fused by lightning.

F. J.

An Electro-dynamometer for Measuring Large Currents.

By W. N. Hill, Chemist, U.S. Torpedo Station.

(American Journal of Science, 3rd series, vol. xix., p. 10.)

This instrument consists of two coils of copper strip, mounted vertically and in parallel direction on a firm base; centrally between these is suspended, by means of a silk thread, a smaller coil, composed of copper strip, the ends being suitably introduced into mercury cups, by which connection is made to the fixed coils, so that the current to be measured passes through all in series. A light horizontal arm is rigidly fixed to the movable coil, at right

angles to which are fastened two silk threads on opposite sides, passing over friction rollers, and sustaining equal balance pans. When a current passes through the instrument, the suspended coil is deflected against a stop, and is brought back to zero by adding weights to one or other of the pans; the intensity of the current is proportional to the square root of the weight required. The constant of the instrument can be determined in absolute measure, or by any of the usual methods. The Author refers to a similar instrument by Trowbridge, but with torsion head for bringing the suspended coil to zero; he has used this instrument in experimental research at the Torpedo School, but fails to point out the superiority of his instrument over the ordinary and more compact forms of electro-dynamometer with torsion head.

F. J.

Galvanometer by Hipp of Neuchatel for Measuring Currents of High Intensity. By E. HAGENBACH.

(Zeitschrift für Angewandte Electricitätslehre, vol. ii., p. 64.)

This galvanometer is constructed in the form of the small circular box galvanometers used in telegraph work; the current passes through a copper band 20 millimètres wide and 1 millimètre thick (9·78 inches by 0·039 inch) which is doubled once, with a cardboard strip between, under the needle, and terminates in two connection screws. The deflecting force acting on the needle is thus due to the difference of the effect of the two parts at slightly different distances. The deflections necessarily require calibrating; the instrument, however, affords a simple galvanoscope, for use with dynamo-electric machines where accuracy is not of special importance. F. J.

[NOTE. Care must be taken in using such instruments for the measurement of strong currents, that the wires, before connection to the terminals, run parallel and close together so as to eliminate their own effect on the magnetic needle, which otherwise might overpower that of the instrument itself.—F. J.]

On the Character and Intensity of the Rays Emitted by Glowing Platinum.

Upon an Optical Method for the Measurement of High Temperatures. By E. L. NICHOLS, Ph.D. (Göttingen).

(American Journal of Science, 3rd series, vol. xviii., p. 446, and vol. xix., p. 42.)

The Author first details his experiments with the purpose of determining for platinum the value of function I in Kirchoff's equation for the emission and absorption of radiant heat, viz.:—

$$\frac{E}{A} = I\,\frac{w_1\,w_2}{S_1{}^2}.$$

This demanded the measurement of the intensity of the rays of all wave-lengths at all temperatures, and this was effected by comparing those emitted from a platinum wire at a fixed temperature, with a similar wire always kept at a constant temperature. The heating effect was obtained from a battery current, which could be regulated by a sensitive galvanometer and resistance coils, and so maintained at an uniform intensity. The temperature was stated in what the Author terms "platinum degrees," the unit being that difference in temperature which causes a linear variation in the wire of 1 : 1·00000866; the expansion of a short central portion of the total heated wire being observed by Helmholtz's ophthalmometer, the fiducial marks being obtained by twisting a turn of very fine platinum wire round the 0·4 millimètre wire used for the experiments, which marks were easily visible at all temperatures. Kitar's leucoscope was also employed to observe any qualitative difference in the wire kept at constant temperature. The comparison of the intensities of the rays of different wave-lengths was effected by the use of a spectrophotometer. The results thus obtained were then compared with the intensities of similar rays of sunlight, Lamansky's values for the latter being adopted. The results are plotted in two sets of curves, one showing the comparative intensities of various parts of the spectrum at constant temperature, the other the influence of temperature on the intensity of individual rays.

The directions of these curves seem to denote that rays of all wave-lengths begin to be emitted at some low temperature (absolute zero?), and it is only due to want of sensitiveness in the eye, or the various instruments in use, that they appear gradually as the temperature rises.

From the results thus obtained, the Author hopes to develop his method for obtaining for a given substance its radiating power as a function of the temperature. M. Crova[1] has suggested, among others, a similar method.

For general discussion, all bodies may be divided into four classes, as regards their absorptive power (A).

1. A is constant for all wave-lengths and all temperatures, *e.g.*, an ideal "black body."

2. A varies with the temperature, but is the same for all wave-lengths, *e.g.*, some transparent substances.

3. A varies with the temperature, and is different for different rays, but the ratio of such difference is independent of the temperature, *e.g.*, probably all other solid bodies.

4. A varies with temperature and wave-length, and the above ratio is a function of the temperature, *e.g.*, all gaseous bodies, as the abundant researches in their spectra show.

The Author has experimentally determined the absorptive power of platinum for the rays of the visible spectrum at 1650° C. (Pt. thermometer). He first finds that the relative intensities of the

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[1] "Comptes rendus de l'Académie des Sciences," vol. lxxxvii., p. 322.

various rays at that temperature are similar to those emitted by a petroleum lamp; then, by comparing the rays from a single lamp with those from a similar one with its real image superimposed by a mirror, eliminating the absorptive effect of chimney and mirror, he obtains for the absorptive capacity of the flame 0·6432, and then, by comparison for platinum at the above temperature, the value 0·7597.

De la Provostaye and Desain,[1] give as the reflecting power of cold platinum the value 0·677; so that the absorptive power would be 0·323, which shows that the absorptive capacity increases with the temperature. The fact that Jacques has discovered that the position in the spectrum of maximum thermal intensity is a function of the substance and independent of the temperature, justifies the conclusion above that all solid bodies belong to the first three classes as regards absorptive capacity.

The further steps necessary for the application of the results already obtained, are to find a general law for the changes of A, or to determine it for particular substances, and then to obtain a satisfactory comparison of the "platinum degrees," with those of the Centigrade air thermometer. At present Matthiessen's formula for the expansion of platinum, viz.: $l_t = l_0$ has been obtained $(1 + 0{\cdot}00000851\,t + 0{\cdot}0000000035\,t^2)$, between 0 and 200° C.

F. J.

On the Absorptive and Emissive Power of Flames; and on the Temperature of the Voltaic Arc. By F. Rossetti.

(Annales de Chimie et de Physique, 5th series, vol. xviii., p. 457.)

The first portion of the Paper recounts the experiments conducted on Bunsen burners, arranged so as to give a wide fantail flame of 1 centimètre thickness, and on ordinary luminous gas flames; the thermal effect being measured by a thermopile and delicate reflecting galvanometer. The temperatures were deduced from the following formula, which the Author has demonstrated in a previous Paper[2]:—

$$Y = m\,T^2\,(T - \Theta) - n\,(T - \Theta),$$

where Y is the galvanometer reading when the radiating source subtends an angle at the thermopile equal to that subtended by the sun at the earth, T the absolute temperature of the radiating source, and Θ that of the medium surrounding the thermopile, m and n constants depending on the sensitiveness of the galvanometer and thermopile. The results obtained are as follow: The absorptive power of flames is small for those rays emitted

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[1] "Comptes rendus de l'Académie des Sciences," vol. xxxi., p. 512; also "Annales de Chimie et de Physique," III., vol. xxx., p. 276.

[2] "Experimental Researches on the Temperature of the Sun." "Annales de Chimie et de Physique," June 1879.

by similar flames, and is the same for the pale blue Bunsen flame, and that of an ordinary gaslight, the value for a thickness of 1 centimètre being $a = 0 \cdot 135$, and increasing with the thickness of the flame. The intensity of radiation can be easily expressed as a function of the transparency $(1 - a)$ for any particular thickness, *vide* the following formula:—

$$Y = a \frac{1 - k^d}{- \log_e k},$$

where a is a constant depending on the nature of the flame (for Bunsen flame, 0·20153, for luminous flame, 0·25741), k is the coefficient of transparency, 0·865, and d the thickness of the flame in centimètres; for an infinite thickness the transparency is equal to zero, that is all rays are absorbed which proceed from a similar source. It is to be noted that Allard has found the same value for the coefficient of absorption for the visual rays, showing that the absorption is equal for the thermal and visual rays.

The absolute (that of a flame of infinite thickness) emissive power of white luminous gas flames is equal to unity, or to that of lampblack at the same temperature; for the Bunsen flame the value is 0·3219. The relative emissive power of a flame of definite thickness can be obtained by multiplying the ratio between the intensity of its radiation, and the maximum (from an infinite thickness) intensity by the number representing its absolute emissive power. The absolute values are reached by a flame 1 mètre thick. From the second part of the Paper it is found that the electric light is composed of two kinds of rays, the one being those emitted by the incandescent carbon points, the other from the arc maintained between them, the former giving an intensely white light, and the latter a blue light, combining to form the familiar bluish white light of electric illumination. The temperatures of the two polar extremities are different, and if their emissive power be taken as equal to that of lampblack, the temperature of the extremity of the positive carbon will be 3,900° C., and of the negative 3,150° C.; and as the arc has the same emissive power as the blue Bunsen flame its temperature will be 4,800° C.; these values are also found to be independent of the thickness of the arc and of the strength of the current.

F. J.

On Motion Produced by the Diffusion of Gases and Liquids.

By H. SAINTE-CLAIRE DEVILLE.

(Comptes rendus de l'Académie des Sciences, vol. xc., p. 18.)

If a tube of platinum or cast steel, maintained at a temperature above 1,000° C., be filled with hydrogen, and surrounded, by means of a bell jar, with nitrogen, a vacuum of very few millimètres' pressure will be produced by the hydrogen passing out of the

tube; if the gases be reversed, or the nitrogen be inside the tube, and the hydrogen outside, a pressure of two atmospheres will be produced by the hydrogen passing in. The Author attributes this to the power of dissolving hydrogen gas possessed by the metals at that temperature, and illustrates this by the similar effect which is produced by ammoniacal gas being soluble in water; thus if a U tube, closed at one end, filled half way up each leg to the same level with water, be then surrounded with ammoniacal gas by means of a bell jar, the gas will be dissolved in the water, and on passing into the closed tube will be given up again until a pressure of two atmospheres is reached. Now by suitable valves and cocks, either of the above methods could be used for raising water, in one case as an exhaust, in the other as a force pump; and the Author gives simple diagrams showing the necessary arrangement. A similar effect can also be produced with liquids by means of a dialyser.

The question then arises, is not the diffusion of gases simply a solution of one in the other? The above phenomena and the discovery of oxygen in silver show that the property of dissolving gases belongs to all forms of matter.

F. J.

On a new Form of Luminous Tubes. By M. Trève.

(Comptes rendus de l'Académie des Sciences, vol. xc., p. 36.)

The well-known crackling sound produced on charging and discharging tin-foil condensers appears to be due to the air which is retained between the lamina, for by subjecting the condensers to a pressure sufficient to expel this air, this effect may be removed. Led by the above fact, the Author has introduced a small condenser of such construction into a Geissler tube, and found, on exhausting the air, that the sound gradually diminished, and finally, at a vacuum of 3 to 4 millimètres, vanished, a brilliant white light then appearing "in pearls" from the edges of the lamina, quite different from the usual pale phosphorescent light of the Geissler tubes.

F. J.

On the Specific Heat of Water.

From experiments by Dr. Baumgartner, communicated by Prof. L. Pfaundler.

(Annalen der Physik und Chemie, new series, vol. viii., p. 648.)

The method of mixtures was followed, and from the results obtained, Pfaundler deduces the value

$$C_t = 1 + 0\cdot000307\, t.$$

C_t being the specific heat at t° centigrade.

Appended are the results previously obtained for the specific heat at 100°, that at 0° centigrade being taken as 1.

Regnault	calculated by	himself	1·0130
,,	,,	Bosscha	1·0220
Münchhausen	,,	Wüllner	1·0302
Baumgartner	,,	Pfaundler . . .	1·0307
S. Henrichsen	,,	himself	1·0720
Jamin and Amaury	,,	themselves . . .	1·1220
Marie Stamo	,,	himself	1·1255

F. J.

Experiments on Different Kinds of American and Russian Kerosene. By Dr. Bil.

(Zapiesky Imperatorskavo Russkavo Tekhnitcheskavo Obstchestva, 1879, part i., Tekhnitcheskia Bessedy, &c., p. 43.)

The Author states the wealth of petroleum in the Caucasus to be so great as to make it possible for Russia to supply all Europe. In North America there are two thousand wells, half of which are dried up. The produce of these wells, in the interval between 1860–1875, was officially stated at 3,350 million gallons of raw petroleum, or 12½ million centners a year. The Caucasus possessed only seventy-eight wells in 1875, which produced, on an average, 2,100,000 centners; therefore the annual produce of a Caucasian is three times as great as that of an American well. It is necessary to add that the wells are only 200 feet deep in the Caucasus, whereas in America they vary in depth from 1,000 feet to 1,300 feet. In proof of the superiority of the Caucasian petroleum, the Author states that he has made experiments in both, with the assistance of Dr. Willm, and that the result has proved a total absence of tar in the former.

Equal quantities of four kinds of American petroleum give, relatively, 1,000, 1,075, 1,140, and 1,190 units of light. Equal quantities of four kinds of Caucasian petroleum produce, relatively, 1,250, 1,350, 1,395 units of light. At the Congress of English Petroleum Dealers, held at Liverpool in January 1879, Mr. Lockwood made the important statement, that, at present, only 25 per cent. of the whole of the American petroleum produced was obtained from New York, the rest came from the new wells at Bradford; that originally the exports were all drawn from the former State, and the deterioration in quality of American petroleum was due to this fact. The Author contends that American petroleum is too inflammable and does not burn well. American petroleum inflames at 24° Réaumur (86° Fahrenheit), whereas the flashing point established in Dr. Buchenau's Report, 1870, is 30° (100° Fahrenheit), and though it burns brightly enough for a time, it gradually grows dimmer, and no raising of the wick will restore its original brightness. To discover the reason for these phenomena, and to determine the components of Russian petroleum

(which is one-third cheaper than American), the Author has subjected them to comparative analysis, from which it appears that Russian petroleum has at present no constant temperature for the flashing point. This is attributable to the fact that Russian manufacturers endeavour to make their petroleum resemble the American in point of weight as much as possible. The Author deprecates the action of the Russian manufacturers, and maintains that the vaporisation of petroleum and its point of inflammation do not depend on its specific gravity but on its temperature of vaporisation. As a result of his experience the Author feels justified in laying down the following rules for the manufacture of Russian petroleum:

1. The repeated distillation at present practised at large petroleum factories must be discontinued.
2. Distillation must be based on the temperature of vaporisation and not on the specific gravity of petroleum.
3. The lowest temperature of flashing point must be 30° Réaumur = 100° Fahrenheit.
4. In determining this temperature it is indispensable to apply a small flame to the oil now and then.

E. A. B. H.

The Naphtha Industry. By K. Leesenko.

Professor at the School of Mines, and President of the First Division of the Russian Imperial Technical Society, 1878.

(Zapiesky Imperatorskavo Russkavo Tekhnitcheskavo Obstchestva, 1878, vol. 12, p. 108 *et seq.*)

The Author remarks that, although the diffusion of naphtha may be traced over the greater part of the globe, yet it can only be profitably and extensively worked along the course of the Alleghany in North America, and in Russia at the feet of the northern and southern slopes of the Caucasian chain.

A considerable portion of the Paper is devoted to a minute description of the North American oil region, after which the Caucasian deposits are discussed. The official estimate of the area of the oil-bearing strata is 14,000 square miles, but there does not appear to be trustworthy data for any such estimate. At the present moment the oil is only worked at Baku, on the south-east end of the Caucasian mountains, and Kertch, on the Kouban river, at the north-western extremity, and in the neighbourhood Zarskia Kolodza, about the centre of the south-western slopes. The oil is found in the tertiary deposits overlying the miocene formations.

The bore-holes are from 280 to 350 feet deep, and the specific gravity of the oil ranges from 0·850 to 0·900. It is worthy of note that the oil region is also remarkable for thermal springs, mud volcanoes, salt springs, and deposits of sulphur.

The produce of the oil wells in 1875 was as under—

	Wells.	Poods.
In the Kouban district	42	230,500
" Tersk "	29	22,160
" Dagestan "	11	6,200
" Apsheron peninsula (Baku) . .	119	6,265,728
" south of Baku on shores of Caspian	72	125,000
	273 =	6,649,588
		= 105,550 tons.

The wells about Baku are extremely productive. Some of the natural springs, running to waste, have formed a lake, still in existence, 1⅓ mile long, and one of the borings of the Baku Naphtha Co., only 238 feet deep, yielded for two years 160 tons of oil daily.

The Author next discusses the phenomena of gas and salt water being found associated with oil, and gives explanations based on the geological formations in which the borings occur.

The chemical composition and physical properties of naphtha, through all its wide ranges, from a thin, feebly-coloured fluid, to deposits of solid mineral pitch or asphalt, are next considered; numerous and valuable tables are given, showing much patient investigation and research.

The consideration of the various theories which have been advanced respecting the origin of petroleum occupies a considerable space in the treatise, and cannot fail to give valuable information to those interested in the industry.

The earlier stages of naphtha mining up to the year 1858, both in America and in the Caucasus, consisted in digging shallow wells 15 or 20 feet deep, allowing the oil and water to accumulate, and absorbing the former by means of thick woollen wicks, from which it was afterwards expressed, or by collecting the produce of several wells into a tank, and skimming off the oil as it floated to the surface of the mixed liquid. In the Caucasus, evidence has been found of the extreme antiquity of some wells worked by the Parsee fire-worshippers.

The first boring for oil was made in Pennsylvania in 1859, and in the Caucasus in 1864; and although the number of bore-holes is still small, yet by far the greater quantity of oil produced is yielded by them.

Boring apparatus may be divided into two systems, the impact and the revolving, and the former subdivided into the rod and rope methods. Each system has its special advantages, depending on the nature of the ground.

Detailed descriptions, illustrated by plates, are given of the structures and machinery employed, and the boring tools and pumping apparatus used.

The Author describes the operations connected with the production of the various qualities of oil from the crude naphtha. The theory of distillation is investigated: it is shown that naphtha

consists of a mixture of various hydro-carbons, the boiling point of which ranges from 0° to 400°. When heated, the lighter oils, or mineral essences, are first distilled; then the lighter and heavier illuminating oils; next the lubricating oils and paraffin oils; and finally, when the residue is raised to a red heat, a small quantity of heavy oil is given off, and a residuum of coke remains in the retort.

The complete separation into various qualities can only be attained after successive distillations, as the products of the first operation contain oils both heavier and higher than the standard aimed at.

Distillation should be carried on as slowly, and at as low a temperature as possible. A vacuum apparatus has been used with success. The temperatures at which the various qualities of oil are distilled, and their specific gravities, are given, and a minute description of the stills and condensers ordinarily used. These are classed under three heads—those acting intermittently, or distilling by charges; those in which the process is continuous, and those in which steam is used. The products of distillation have, for the most part, to be refined. This is generally done by treating the oils with sulphuric acid, neutralised afterwards by means of caustic soda. The theory of the process is stated to be obscure. Other chemical and mechanical methods are discussed, and the apparatus used is minutely described. The light oils are further treated by distillation, and several varieties of naphtha produced, the boiling points and specific gravities of which are very low. The treatment of the heavy oils destined to be used as lubricants, and of the residues of the distilling apparatus, is fully described. The general arrangement of rectifying factories is described, and illustrated by drawings.

A large portion of the Paper is devoted to descriptions of the various kinds of lamps that have been invented for consuming the different descriptions of oil. The principles involved are discussed, and the modifications needed to suit the Russian oils are pointed out. The modes of ascertaining the flashing points of oils is fully explained, and the importance of accuracy, with the view to the establishment of standards, pointed out.

The Author concludes with an exhaustive review of the methods employed, both in America and in Russia, for the storing and transport of naphtha; the cost, construction, and safety of the vessels used for holding it; and draws a comparison of the cost of obtaining and working petroleum in America and the Caucasus.

W. A.

On the Inflammability and Lubricating Qualities of the Oils of Commerce. By A. Rieu and J. Jean.

(Bulletin de la Société Industrielle de Mulhouse, 1879, p. 543.)

The objections to vegetable and to animal oils as lubricants are, chiefly, that they readily absorb the oxygen of the air, and become

thickened so as to require to be frequently renewed. Mineral oils, derived from petroleum and from bituminous schists, may be with advantage used in mixture with the animal and vegetable oils, for diminishing the tendency to thicken. But mineral oils for lubrication are subject to the disadvantages of inferiority of density and too great inflammability. Boghead oils ignite at temperatures of from 300° to 370° Fahrenheit; petroleum oils have the same range of temperature for inflammation, though some oils ignite at temperatures of about 190° Fahrenheit. Vegetable and animal oils, on the contrary, do not burn until they attain temperatures of from 400° to 600°. For mixtures of vegetable oils and mineral oils, the point of ignition appears to be ruled very much by that of the mineral oil. The same remark applies to mixtures of animal oils and mineral oils. The test of inflammability employed was the placing of a light at a distance of 1 centimètre, or $\frac{4}{10}$ inch from the surface.

With respect to the lubricating qualities of oils, the Authors state that animal and vegetable oils are composed of two fatty bodies, stearine and oleine, of which the former is solid, and the latter fluid, at ordinary temperatures. The proportions average as follows:—

	Animal Oils.	Vegetable Oils.
Stearine	45	33 to 25
Oleine	50	65 „ 70
Impurities	5	2 „ 5
	100	100

The Authors conclude, from the results of their experiments, that colza oil is not suited for lubricating purposes, and that olive oil is the best for the purpose. The more fluid an oil is, the less friction takes place. The coefficient of friction is increased as the temperature is lower, and the density is greater; it is also more variable with the pressure as the density is less. At speeds varying from 60 to 190 revolutions per minute, under a constant pressure of 142 lbs. per square inch, the frictional resistance with olive oil, at the temperature of 60° Fahrenheit, increased at a uniform rate with the speed; and, on the contrary, at a uniform speed of 60 revolutions per minute, and under pressures of from 14 lbs. to 280 lbs. per square inch, at the temperature of 68° the frictional resistance increased nearly uniformly with the pressure.

Napoli's apparatus was employed in the experiments on lubrication. A circular plate of wrought iron, 20 inches in diameter, revolves on a vertical spindle; a similar plate of gun-metal, weighing 110 lbs., is placed upon the iron plate, and is maintained at rest. By means of a lever, the load or pressure on the upper plate may be regulated as required. The resistance is measured by a dynamometer, and registered on a sheet of paper.

D. K. C.

Note on a Log with Revolving Hollow Hemispheres on the Principle of Robinson's Anemometer.

(Revue Maritime et Coloniale, November 1879, p. 465.)

The principle of the screw is nearly always made use of in the construction of logs for ascertaining the speed of vessels or of submarine currents. Its use is, however, open to two grave objections; 1st. A deformation of the blades, scarcely visible to the eye, causes a serious change in the pitch, and leads to false results; and 2nd, a slight variation in the resistance to be overcome modifies materially the coefficient of slip. Robinson's anemometer has been used for some time to measure the velocity of the wind. As is well known, this instrument consists of four arms cross-shaped, and fixed to a central pivot. At the end of each arm is a hollow hemisphere fixed in such a way that, when the instrument revolves, the convex side of each hemisphere is the first to meet the wind.[1] The impact of the air on the hollow side of a hemispherical cup is twice as great as on the convex side, and Robinson has proved experimentally, that whatever the velocity of the wind, or the radius of the arms and hollow cups, the speed of the centres of these latter is always a constant fraction (nearly $\frac{1}{3}$) of the speed of the wind. When used in water instead of air, the same law appears to hold good for all speeds between 2 and 12 knots an hour. When employed as a log, the most important point to be determined was the influence of friction on the rotation of the instrument. The experiments made to determine this point gave very satisfactory results, for the ratio of moving force to the resistance of friction is so great that any little variations in the latter do not sensibly affect the precision required in practice. In consequence of the inequality of the waves, and the motion of pitching and rolling, all idea of fixing the instrument to the hull of the vessel had to be abandoned, and towing in rear of the vessel as with an ordinary log was resorted to. Unfortunately, this arrangement entailed either a submerged counter to register velocities, or else an electric transmission which should register the revolutions on board the vessel.[2] This latter mode was made use of as being the more convenient, but many experiments were necessary before a safe system was discovered. The following plan has been found to work well in practice. A Leclanché battery of two cells is arranged for intensity, and the carbon pole is connected, by a wire attached to an electric bell, with

[1] *Vide* Paper on Anemometers, by the Rev. F. W. Stow, Quarterly Journal of the Meteorological Society, vol. i., p. 41; also evidence of Professor Stokes in the Tay Bridge Inquiry, "Engineering," May 7th, 1880, pp. 363 and 364.

[2] *Vide* Proceedings of the Royal Society, vol. xxviii., p. 114. Mr. G. F. Deacon and Mr. H. Law have both used electric current meters with submerged counters. —Sec. Inst. C.E.

the hull of the ship. The zinc pole is connected by an isolated wire with a cylinder on the axle of the revolving vanes. This cylinder is formed half of copper and half of lignum vitæ or bone. In the direction of the wire from the carbon pole the current has scarcely any resistance to overcome, for the hull of the vessel may be considered as a conductor of infinite section; but in the direction of the sea the communication is made by a limited surface, and the intensity of the current towards the pile is, in a great measure, regulated by the dimensions of the submerged metallic surfaces in connection with the conductor. When the end of this latter bears on the lignum-vitæ half of the cylinder, the section in contact with the water is reduced to a few millimètres, and the current is consequently too feeble to attract the striker of the bell; but when it touches the copper half, the communication with the sea becomes the whole surface of the instrument, the current becomes strong, and the hammer strikes the bell. This is repeated once in every revolution of the anemometer. To ascertain the speed of a vessel, it is necessary, 1st, to tow the log; 2nd, to put the battery in circuit; 3rd, to reverse a sand-glass, or to make use of any other species of chronograph; and 4th, to count the number of blows on the bell during the time the chronograph is observed. The dimensions of the log and sand-glass are so chosen, that ten strikes on the bell during the time occupied for the sand to flow out corresponds to a speed of 1 knot per hour. The Author gives drawings of the instrument and calculations for the dimensions of its parts. The apparatus was used with such success during the voyage of the French frigate "Magicienne," that the old-fashioned log was dispensed with.

G. C. V. H.

Krupp's Gunnery Experiments at Meppen.

(Official Report. Mittheilungen über Gegenstände des Artillerie- und Genie- Wesens, 1879, p. 481.)

The firm of Friedrich Krupp, of Essen, carried out, in August 1879, an important series of experiments at Meppen, in Hanover, which was remarkable on account of the high initial velocities attained with some of the guns.

The report contains: i. A description of the shooting range; ii. A detailed account, with dimensions of all the guns and carriages experimented upon; iii. A description of the way in which the experiments were carried out; iv. Conclusions drawn by the firm from the results of the experiments.

Annexed will be found a Table giving the leading data of all the most interesting guns, and their ammunition, together with the initial velocities attained and energies developed.

Calibre of Gun.	Length of Gun.	Length of Bore.	Weight of Gun including Breech-piece.	Number of Grooves.	Depth of Grooves.	Width of Grooves.	Width of Lands.	Pitch of Rifling.	Weight of Charge.	Weight of Projectile.
Mm.	Mm.	Mm.	Kilog.		Mm.	Mm.	Mm.		Kilog.	Kilog.
400[1]	10,000	8,711	72,000	90	2	4·5	9·45	One turn in 45 calibres	205 200	776·7 642·8
355[2]	8,880	7,740	52,000	80	2	4·5	..	One turn in 16 mètres	..	..
240[3]	6,120	5,410	18,000	54	1·5	4	..	One turn in 45 calibres	75 75	160(1) 136(2)
155[3]	..	..	3,529	36	..	..	..	One turn in 45 calibres	..	..
149·1[4]	4,200	3,780	3,960	36	1·5	3·5	9·5	One turn in 25 calibres	15 15	51(3) 40(4)
105[5]	2,850	2,574	1,060	32	1·25	3·5	6·8	One turn in 25 calibres	4·2	16
96[6]	2,500	2,260	625	32	1·0	3·0	6·4	One turn in 25 calibres	2·7	12
87[7]	4,350	4,085	1,265	24	1·25	3·0	8·4	One turn in 30 calibres	3·5 3·5	10 6·8

1 This gun is intended for coast defence. Projectile—armour-piercing shell. Prismatic powder with one perforation, specific gravity = 1·75.

2 This gun was only tried for accuracy and speed in firing. A shot can be fired every 2¼ minutes.

3 When fired with steel shell against a target composed of 305 millimètres of wrought iron, and 55 millimètres of timber, and a second wrought-iron plate, 205 millimètres thick, the projectile penetrated completely, and travelled 2,200 mètres beyond the target. Projectile—(1) armour-piercing shell; (2) common shell. Prismatic powder with one perforation, specific gravity = 1·75.

Length of Chamber.	Diameter of Chamber.	Cubic contents of Chamber.	Cubic Contents per lb. of contained Charge.	Velocity of Projectile, initial.	Energy of Shot.	Energy per centimètre of Shot's circumference.	Energy per sq. centimètre of Shot's Cross Section.	Energy per Kilogramme of Powder.	Energy per Kilogramme of Weight of Gun.	Pressure of Powder Gas.
Mm.	Mm.	C. dec.	C. dec.	Mètres.	M. tons.	M. tons.	M. tons.	M. tons.	M. Kil.	Atmos.
1,558·25	440	236·9	1·16	502·4	9,992·0	79·5	7·95	48·7	138·8	2,480
1,560·4		237·3	1·19	536·8	9,440·6	75·13	7·51	47·2	131·1	2,500
..	..	..	..	..	..	..	..	..	..	..
1,274·4	286	81·87	1·09	576·6	2,711·2	35·96	5·99	36·15	150·6	2,550
1,278·5	286	82·14	1·10	606·9	2,553·2	33·86	5·64	34·04	141·8	2,565
..	..	..	..	..	..	..	..	..	..	..
727	175	17·49	1·17	508·6	672·4	14·36	3·85	44·83	169·8	2,541
727	175	17·49	1·17	559·35	637·9	13·62	3·65	42·53	161·1	2,462
505·8	130	6·34	1·51	456·6	170·0	5·15	1·96	40·48	160·4	1,960
344	106	3·02	1·12	452·5	125·2	4·15	1·73	46·38	200·4	2,100
339·4	150	4·54	1·30	557·5	158·4	5·79	2·67	45·26	125·2	1,765
344·6	150	4·54	1·30	639·6	141·8	5·19	2·39	40·51	112·4	1,540

[4] This gun was only tried for accuracy. Projectile—([3]) armour-piercing shell; ([4]) common shell. Prismatic powder with seven perforations, specific gravity = 1·75.

[5] Projectile—common shell. Prismatic powder with seven perforations, specific gravity = 1·64.

[6] This is a field gun of about the same weight as the English 16-pr., but of double the power. Projectile—common shell. Large grain powder, the grains measuring 13 to 16 millimètres.

[7] Projectile—common shell. Large grain powder, the grains measuring 10 to 13 millimètres.

N.B.—1 millimètre = 0·039 inch.

G. C. V. H.

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TO THE

MINUTES OF PROCEEDINGS,

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